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DURABILITY AND FIRE-SPREAD ASPECTS OF PLASTIC PIPE SYSTEMS.(U)
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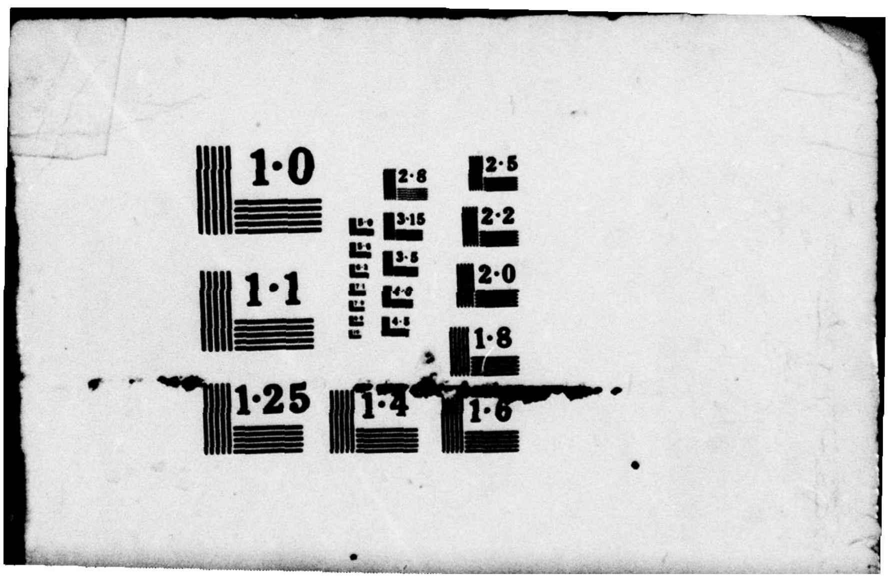
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TECHNICAL REPORT M-264
July 1979

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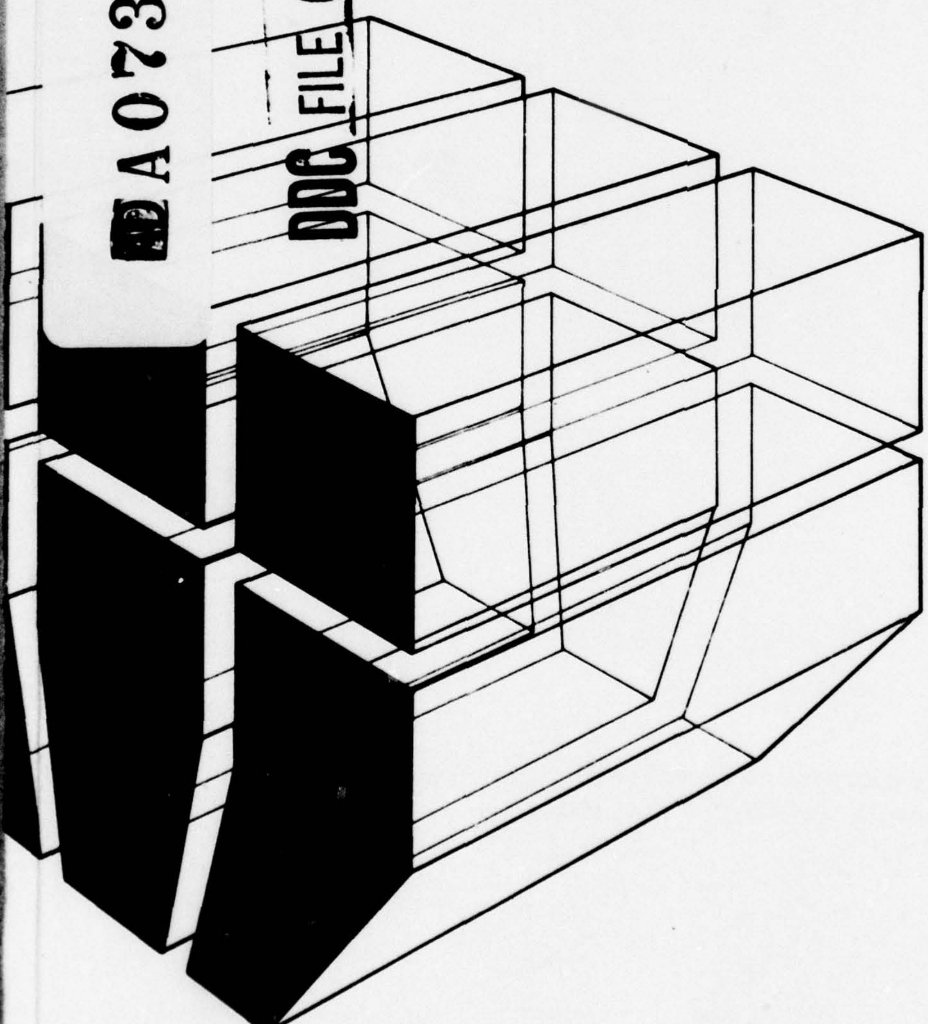

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER (14) CERL-TR-M-264	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) DURABILITY AND FIRE-SPREAD ASPECTS OF PLASTIC PIPE SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED FINAL rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Alvin/Smith, R. Brady/Williamson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005, Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) A4762731AT41-T7-008 (17)
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE (11) July 1979
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 68p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

plastic pipe
fire resistance
performance tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the findings of two studies of commercially available thermoplastic pipe now in widespread use for water distribution, drain-waste-vent (DWV), sewage, and plumbing systems.

One study dealt with the long-term performance of plastic pipe and drew information from users' experience. The other study concerned accumulation of test data on fire spread in structures having plastic pipe in interior plumbing and DWV systems.

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CONT Results of the two studies indicate that plastic pipe is very durable in long-term service as predicted by short-term tests and that while most plastic pipe will burn in established building fires, the fire spread potential is not great. Designs that further limit fire spread are given.

FOREWORD

This research was conducted for the Directorate of Military Programs, Office of the Chief of Engineers (OCE) under Project A4762731AT41, "Design, Construction, and Operation and Maintenance Technology for Military Construction"; Task T7, "Military Construction Materials"; Work Unit 008, "Field Jointing of Plastic Pipe." The applicable QCR is 1.02.001(2). The OCE Technical Monitor for the study is Mr. Harold McCauley.

The work was performed by the Engineering Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. Dr. G. R. Williamson is Chief of EM.

Appreciation is expressed to Dr. W. L. Ryan of the Indian Health Service, Window Rock, AZ, and Mr. Chuck Bowman, also of the Indian Health Service, Albuquerque, NM, for information provided on their long-term experience with plastic pipe for water distribution; and to Dr. R. Brady Williamson, J. Bradford Corporation, Berkeley, CA, for his work on the fire spread aspects of plastic pipe in buildings.

Col. J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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DURABILITY AND FIRE-SPREAD ASPECTS OF PLASTIC PIPE SYSTEMS

1 INTRODUCTION

Background

The widespread acceptance and use of various types of plastic pipe was established in a previous study [1]*. However, that study did not specifically address two very important aspects of plastic pipe: (1) its long-term durability and reliability, and (2) the potential for fire spread in buildings caused by the use of plastic plumbing (including DWV).

Durability of plastic pipe cannot be assessed based on performance alone since it has only been in use 40 years [2]. Therefore, short-term tests have been developed to predict long-term performance, and these predictions have proved to be reasonable and acceptable [2].

Fire spread in buildings has been a major concern of designers for many years. The increased use of flammable materials in applications such as coverings, carpet, insulation, furniture, and plumbing has prompted building code officials to establish criteria for flammability properties of materials and the design of structures in an attempt to limit the spread of fire within the structure.

Durability and fire-spread propensity of plastic pipe are both of concern to the Corps of Engineers in determining authorized uses of plastic pipe.

Objective

The overall objective of this study was to compile information on thermoplastic pipe for the Office of the Chief of Engineers (OCE), to serve as a basis for introducing the material into military construction. This report completes the compilation by presenting data on the durability and flame-spread properties of the pipe.

Approach

Information on durability was gathered by reviewing the literature for studies that have been conducted throughout the world and by interviewing long-term users of plastic pipe (Chapter 2). Fire-spread data were gathered from a review of all available test reports on the subject (Chapter 3 and the appendix).

*Bracketed numbers refer to references listed on page 11.

Scope

This study covers only thermoplastic pipe, although many of the findings relate to thermoset plastic pipe as well. The study was limited to durability and fire-spread aspects and relied on existing information. Pipe material that had been in service for a number of years was not tested, since plastic materials and pipe production methods have improved considerably in the past few years. Comparing old plastic pipe in service with newly produced pipe materials of the same generic type could thus lead to false conclusions that the plastic pipe in service had deteriorated when in fact it had not.

Mode of Technology Transfer

The results of this study will impact the following Corps of Engineers guide specifications:

CE 300.01	Plumbing, General Purpose
CE 300.02	Plumbing, Hospital
CE 301.37	Air Supply and Distribution System
CE 501	Waterlines
CE 900	Gas Distribution Systems
CE 15302	Sewers, Sanitary Gravity
CE 02502	Subdrainage Systems

Safety

The material discussed in this report does not represent a hazard to the installer or user.

2 DURABILITY OF PLASTIC PIPE IN SERVICE

Early Use of Thermoplastics

Polyvinyl chloride (PVC) was first produced in Germany in the early 1930s and first used as pipe in 1938. Thirty years later Engle [2] reported that hundreds of miles of the original water supply pipe was still in good condition. In the same article, Engle stated that he had used phenol-formaldehyde [phenolic] pipe in chemical plant applications as early as 1942.

Polyethylene (PE) pipe became available in the early 1940s and was used by the Germans for water distribution in about 1948 [3]. One of its earliest uses in the United States was for gas pipe; the Southern California

Gas Company installed a system in 1947 after 5 years of testing [4]. Butyrate pipe was used by the same company in Los Angeles in 1941 [5]. Pacific Gas and Electric Company used cellulose acetate butyrate pipe as a substitute for copper in 1951 [6]; more general use for gas distribution began in the United States about 1958 [7].

Water distribution using plastic pipe began in the United States in Skaget County, Washington in 1952 [8]. Other countries began using plastic pipe in general water and gas distribution systems at about the same time. In Japan, PVC use began in about 1950 [9]. England commenced use of plastic pipe following World War II [10,7]. The Netherlands and Swedish gas industries were using plastic pipe mains by 1957 [11,7]. In the early 1960s, Australian farmers began using plastic pipe, particularly polyethylene, for stock watering and similar uses [12]. The South Africans began using plastic pipe in the late 1950s for sewerage and drainage applications [13]. The Soviets apparently were also using plastic pipe before the 1960s, since articles on mechanical strength of thermoplastic pressure piping by Bokshitski and co-workers appeared in *Soviet Plastics* in 1962 [14].

Development and Use of Short-Term Tests

Increasing use of plastic pipe for numerous pressure and nonpressure applications stimulated interest in a variety of property studies. Durability, quality and process control, and reliable design factors were identified early as areas demanding study.

Since users of pipe materials expect troublefree service for 50 years or more, emphasis was placed on testing methods that would predict long-term performance of pipe in service. Reinhart reported that the Thermoplastic Pipe Division of the Society of the Plastics Industry established a Working Stress Subcommittee in 1958 [15]. This subcommittee was dedicated to developing a method for estimating long-term strength properties and defining hydrostatic design stress criteria from those properties [16]. Comparable studies carried out in England were reported in 1961 by Gill [17]. In Germany, Neumann and Umminger reported on similar studies in 1959 [18].

Numerous methods of analysis were evaluated to relate short-term measurements to long-term strength properties. Creep phenomena common to thermoplastic materials were well known and understood in terms of viscoelastic response and were shown to be valuable in analysis as described by Faupel [19,20]. Creep of nonpipe specimens tested for long periods confirmed the general viscoelastic response of PVC and PE materials [21]. Nilas and Eifflaender [22] demonstrated proportionality between creep and stress only if stress was small; high stresses caused a change from elastic to plastic strain. Reinhart discussed the method developed by SPI subcommittee [16] in which log stress was plotted versus log time to failure at four temperatures and the stresses selected caused failure between 10 and 10,000 hours. The log-log line would then be extrapolated to 100,000 hours. The tests assumed that a "knee" would occur at some temperature and stress in a time between 10 and 100 hours. If no knee occurred, direct extrapolation to 100,000 hours could be done. When a knee did occur, the test was continued to 10,000 hours and the data plots were then used for the extrapolation. The method was adopted by ASTM and was designated as Method D-1598.

The stress regression technique described above is only one method of evaluating the performance of pipe. Chang developed a reduced time method [23] in which the tests were performed at several temperatures in times of less than 1000 hours. A composite curve and a shift factor curve could be used to predict the long-term burst stress of various plastic pipes at numerous temperatures and times. Another method, developed by Goldfein [24], used a variation of the Larson and Miller equation by introducing a zero strength temperature and K, which was a function of hoop stress. A master curve that related stress versus K was determined experimentally at different levels of stress and temperature. Chang's predictions were based on calculating a value of K from the time and temperature desired and obtaining the corresponding stress from the master curve. The advantage of Chang's method is that short-term data can be used to accurately predict long-term performance. This method is of value since long-term tests are impractical for use in production quality control.

An even faster test is described in ASTM D-1599. A continually increasing internal hydraulic pressure is introduced while the test specimen is constrained in a controlled temperature medium. The pressure application rate is adjusted to give burst failure in about 60 seconds. The short test time allows rapid testing of production specimens. However, Meyer discusses the inadequacy of the short-term rupture test with respect to long-term performance [24]; he suggests that in the short-term test, events occur too rapidly to allow typical plastic response and that results can be misleading.

Nesbeitt evaluated the stress regression mechanism [25] and stated that the technique should be adequate for design purposes since a system would seldom be allowed to operate at more than the design pressure. Occasional water surges are of such short duration that, coupled with the normal safety factor, they should present no problem to plastic pipe (PVC) water distribution systems. Nesbeitt emphasized that while cyclic fatigue must be considered in system design, PVC pipe designed to operate at 160 psi but operating at a more typical 110 psi has such low hoop stress that an infinite number of surge cycles could occur without failure. Finally, Nesbeitt demonstrated that creep induced by internal pressure in PVC pipe designed and operating at 160 psi (with a safety factor of 2.0) occurs so slowly that failure would take thousands of years.

The Soviets [14,26] recognized the somewhat fallacious basis of using constant internal pressure as a means of judging long-term performance. They compiled durability curves of mechanical properties and noted the transition from ductile failure to brittle fracture, particularly in polyethylene. They concluded that it is essential to consider creep under both constant stress and the relaxation of stress. Thus, in calculating the strength of thermoplastic pipes, relationships should be based on linear theory of viscoelasticity with a consideration of stress level included in the calculations.

Acton [27] reported on the technique of accelerating the heat aging of polyethylene and extrapolating test results to predict 10-, 20-, and 50-year performance. This method was partially incorporated into the long-term test method of ASTM-D-1598. Richard and his co-workers [3] discussed the early problems with analyzing creep data and correlating the test results to actual service conditions.

Long-Term Testing and Observation

Concurrent with the development of the test methods described above was the advent of several long-term tests of plastic pipe. Buczala described a 16-year field test of PVC, PE, acrylonitrile butadiene styrene (ABS), cellulose acetate butyrate, nylon, and acetal pipes [28] in which ring tensile testing was used to assess ductility and design stress data. The effects of gas constituents and soil conditions were also evaluated. Conclusions show minor aging effects and little change caused by gases or soil conditions.

A 25-year evaluation of a polyethylene telephone conduit buried between Baltimore and Washington revealed that the tensile strength of the conduit had remained virtually unchanged [29].

The Indian Health Service (IHS) is perhaps the longest term government user of plastic pipe for water distribution. Hundreds of miles of PVC pipe have been installed on Indian reservations from Alaska to Florida in the past 18 years. Installations have been made in virtually all kinds of soils and climates. Pipe sizes range up to 8-in. (.2-m) diameter. IHS has not kept maintenance records on the installations. The water systems are generally turned over to the Indian tribes upon completion, although the IHS would be aware of most problems that occurred. No problems have been noted once a system was installed and passed the initial test. Tie-ins to the systems that had been in service in extremely harsh soils revealed pipe that was apparently unchanged from the time of installation. The IHS is very pronounced in its acceptance of the long-term durability and reliability of PVC pipe for water distribution systems [29].

Other Durability Factors

Other factors affect the durability of plastic pipe in addition to the creep-hoop stress or hydrostatic pressure. These factors include cycling of pressures, weathering, solvent action, deflection, composition of the carried medium, and effects of loads imposed by underground burial.

Pressure cycling such as the normal fluctuations caused by interruptions in flow have not been a source of trouble in operating plastic pipe water distribution systems. The long experience of the IHS had no record or recollection of pipe failure that could be attributed to pressure cycling.

Weathering may occur in two separate phases: stockpile exposure and usage exposure. Outdoor storage of stocks of material may allow adverse exposure of pipe that is not intended for such use. Ultra-violet light can cause the material to become more brittle and impact sensitive [2]. Although colorants are often used in compounded plastics for purposes such as end-use identification, they do not always impart light stability and protection to the polymer [30]. Light-stable colors, including carbon-black, are normally used today for ultra-violet light resistance [31]. One example of such use is in a properly compounded PVC pipe system that is part of an air conditioning system in Florida. The roof-top location has exposed the pipe to more than 20,000 hours of sunlight with temperatures up to 150°F (65°C). The pipe has shown excellent resistance

to weather deterioration and is still giving good service [29].

The action of solvents may reduce service life of plastic pipe. Solvents usually reduce the strength of the plastic by swelling it and destroying intermolecular forces. Solvent degradation normally occurs quickly and results from internal exposure, although in rare cases plastic pipe has failed because of solvent presence in the soil. Manufacturers of plastic pipe have conducted laboratory tests to develop recommendations for use of pipe exposed to solvents. Related to solvent action is the loss of certain compounding and processing aids called plasticizers, which are used mostly in PVC compounds. Plasticizers in pipe manufactured prior to the early 1970s may be leached out or may migrate out of the finished pipe. In either case, some increase in brittleness is likely. Present processing methods either do not require plasticizers or use plasticizers that do not migrate or leach out.

Deflection of pipe caused by either thermal changes, imposed loads, or both is an area of concern because of the general lack of understanding of the phenomenon. Earth loading causes external pressure on buried pipe. The pressure is more pronounced on nonpressure systems such as sewer or drainage installations since there is no compensating internal pressure. Plastic pipe behaves differently from conventional materials such as steel, cast iron, clay or concrete in response to external loads. The conventional materials, being brittle or of high modulus, deflect slightly and fail as soon as their inherent strength is exceeded. Plastic pipe has much lower inherent strength but will deflect downward and outward at the same time, transferring force to the bedding material and effectively reinforcing itself. PVC sewer pipe has been known to deflect as much as 25 percent from its original diameter and still maintain adequate integrity [32]. Durazo presents an excellent discussion of deflection characteristics and necessary design criteria for installations of sewer and drainage systems of plastic pipe [32].

Constituents of transported materials may effect changes in plastic pipe. Benton [33] and others have shown that certain condensates from gases absorbed into the pipe cause the same basic changes as discussed regarding solvents. Benton concludes that rigid PVC pipe should be able to handle most gas distribution without problem. This conclusion was supported by the Southern California Gas Company [4]. Tests conducted by the National Sanitation foundation [34] showed no harmful extraction of material from plastic pipe by water carried in it. Some extraction of heavy metal (lead) has been found in European PVC and in early U.S. production; however, no lead compounds are used in processing U.S. PVC pipe today. Vinyl chloride monomer (VCM), the material from which PVC is made, has recently caused concern as a suspect carcinogen. The fear that unreacted VCM would migrate from PVC pipe into water was found to be ungrounded in extensive studies [35].

Structural loading of buried pipes has been studied by Moser [36] and others [37,38]. The burial response tests, conducted under laboratory conditions, showed essentially the same type of response for steel, PVC, and PE pipe in dense soils. Backfill or bedding is more compressible in loose soils, allowing the great deflections previously discussed. Other factors, such as soil friction, must be considered in installation design. If the soil is hydrostatic, a design basis that accounts for soil water pressure must be used. Satisfactory performance may be assured if present burial standards as identified by Wyly [39] in the ASTM (D-2321 and D-2774) are followed. Both standard practices require select backfill around the pipe to avoid point loading by stone or other hard debris, and control of trench width and depth configuration.

Problems of termite, rodent, and fungal or bacterial attack on plastic pipe are regarded as minor. The Australian study by Gay and Weatherly [40] showed termite attack in certain areas according to type and population of termites and type of plastics involved. "Hard" plastics such as pipe material (that is normally fairly thick) generally suffer little damage from termite attack; however, rodents have caused some problems [1]. Studies have shown that rodents can chew through pipe but do so only when the pipe blocks access to water or food. Rodent repellents may be used in backfill to deter damage to buried pipe [29]. Since nutrients are absent from plastic pipe materials, fungal or bacterial growth usually does not occur.

3 FIRE SPREAD IN STRUCTURES DUE TO PLASTIC PIPE

Most organic materials are flammable to some degree, depending on composition and configuration of the molecular structure. The materials from which plastic pipe is made (PVC, PE, ABS, etc.) will all burn in established building fires. Since drain, waste, vent

(DWV) systems of plastic pipe are widely accepted by model building codes and regulatory authorities, the concern about fire spread related to the use of plastic pipe in buildings is valid.

A contract was awarded to Dr. R. Brady Williamson for a study of the fire spread aspects of plastic pipe in buildings. The report of that study, which is included as the Appendix, details tests conducted by the National Bureau of Standards, Ohio State University, University of California at Berkeley, and the Experimental Building Station (Australia). Tests of a variety of piping configurations and test conditions are summarized.

The conclusions of these tests show three things: (1) certain specific uses of plastic pipe (in building) have been shown to be safe, (2) certain aspects of fire tests are important in interpreting test results, and (3) the safety of some plastic pipe configurations has not been demonstrated by tests.

4 CONCLUSIONS AND RECOMMENDATIONS

Plastic pipe is durable in service, and process and quality control procedures are available to assure the designer and installer of successful systems. Design criteria for similar systems of other materials are not directly translatable into criteria for plastic pipe.

In approved uses of plastic pipe in buildings and structures, methods and procedures are available and observable that will assure no compromise of fire safety to the building or occupants. Some uses or potential uses, such as concentrated assemblages of plastic pipes, require special tests or treatment to assure fire spread safety.

It is recommended that the Corps of Engineers authorize the use of plastic pipe in installations presently approved by civilian codes. These installations include water distribution, gas distribution, sewer systems, DWV of buildings, drainage and irrigation applications.

Guide specifications or other contractual documents should be composed to guarantee the Corps that qualified installers of plastic pipe are used in order to assure satisfactory performance.

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APPENDIX: REVIEW AND SUMMARY OF THE STATE OF THE ART OF STUDIES ON ROLE OF PLASTIC PIPE IN FIRE SPREAD IN STRUCTURES AND BUILDINGS

1 INTRODUCTION

The objective of this appendix is to identify, compile, and summarize all available test data pertaining to the roles of plastic pipe in fire spread or the potential for fire spread in all classes of buildings and other structures. Plastic pipe has become very popular with architects, engineers, construction specialists, as well as ordinary consumers, since it often offers a substantial savings in costs, corrosion resistance, and other qualities. This report focuses on the fire safety aspects of plastic pipe installed in buildings or other structures.

Fires usually start in buildings with one small item in flames, such as a wastepaper basket or a chair, and then grow in size. If the fire is going to become serious, the small fire which began with a single item eventually grows to suddenly involve the whole room. This instant of total room involvement is called "flashover." This report will focus on the post-flashover performance of plastic pipe. The contribution of plastic pipe to the growth of fire in the compartment of origin will be addressed only briefly since it is automatically treated if the post-flashover performance is evaluated.

The series of events that lead to a serious fire can be broken in many places. The probability of a fire reaching flashover is very small, but a sequence of improbable events can lead to flashover in even the most well-protected areas. The realization that the worst eventuality is not impossible must lead to an evaluation of how a building would respond to a sustained high-intensity fire. This fire performance of the structure is termed "fire resistance" or "fire endurance" and buildings which have been designed with a given level of fire endurance are termed "fire resistant" buildings.

2 POLYMERS AND THEIR USE FOR PIPING

Many different materials are referred to as "plastics." In general they are a subcategory of a larger class of materials known as "polymers," and they represent an attractive material for piping. There are several broad categories of plastics and then there are specific materials which have been widely used for different kinds of pipe. In the following sections certain terms like "thermosetting" and "thermoplastic" will be used to classify the expected fire performance of pipe. The thermosetting pipe can be expected to remain rigid during a fire until it is consumed, while a thermoplastic pipe will collapse after only moderate heating to 200 to 300°C and will often move away from a fire. Then there will be further differentiation of thermoplastics into "crystalline" or "amorphous" materials because the crystalline polymers generally form very fluid liquids when they are melted, while the amorphous polymers are generally more viscous after they soften. Finally, other categories are related to production methods such as "extruded" pipe, "injection molded" fittings, or "structural foam," which become important under certain circumstances.

Other terms are related to the end use of the pipe system. These terms follow the practice of pipe systems in general, and it is assumed that the reader is familiar with these.

The drain, waste and vent (DWV) system of a building represents a substantial quantity of material which traverses through many portions of that building. This use of plastic pipe has received widespread attention since it is a very corrosive environment for ferrous metal pipe and it does not require pressurized service. Both acrylonitrile-butadiene-styrene (ABS) and polyvinyl chloride (PVC) have been used for domestic DWV systems in the United States. In Europe polyolefines (polyethylene or polypropylene) and high impact polystyrenes have been used with generally acceptable results under normal use. There has been little question of the fire safety of these products in the open European literature. The fire safety of domestic DWV systems has been of considerable concern in the United States and many fire tests and experimental programs have addressed the fire problems of these systems. There is also a large scale use in the United States of polyolefin DWV pipe in hospital and laboratory buildings since these crystalline polymers offer substantial resistance to the organic solvents which can be expected in these buildings. As described below, these crystalline polymers require a different treatment than the amorphous polymers.

3 EARLY FIRE GROWTH

The contribution of plastic DWV piping to early fire growth was evaluated by Troxell [1]*. Three mock-ups of ABS DWV systems installed in wood frame construction were exposed to plastic wastebasket ignition sources. In the foreground of Figure A1(a) is a two-story mock-up having a kitchen sink and wooden cabinet in the lower story and a bathroom wash basin connection in the upper story. The location of the ABS DWV piping inside the wall is shown on the surface of the gypsum wallboard. The exterior of the back of the mock-up was covered with tongue and groove redwood siding. There were no special provisions for fire stopping the wall penetrations of the plastic pipe. Wall plates were drilled to provide 1/16-in. clearance, and fire stops within the wall were notched to provide much larger clearances. Another mock-up in Troxell's experimental program is visible in the left-hand background of Figure A1(a).

A photograph of the burning wooden kitchen sink cabinet is shown in Figure A1(b) at approximately 11 minutes into the test. The fire was extinguished after 22 minutes, and the remains of the kitchen cabinet can be seen in Figure A1(c). The redwood siding was removed and is illustrated in Figure A1(d). There was little damage to the ABS piping. The horizontal part of the tee for the sink was partly burned, and approximately 2 feet of the vent pipe above the tee had been elongated to 3 feet and had sagged down and folded over at the tee to close this pipe. Troxell noted that "the very hot fire resulting from the burning of the plywood cabinet so overshadowed the slight flaming of the ABS tee and pipe as to make the ABS fire inconsequential." In discussions of all of the experiments, Troxell noted that "burning of the exposed ABS pipe does not tend to transmit a fire into the stud space." Further, he observed that "the pipe softens when heated, so that it sags or collapses within the stud space and covers the opening in the plate so that the fire generally does not tend to follow the pipe into the stud wall." These early experiments set the background for the more recent ASTM E119 tests of walls containing DWV systems. There were a number of ad hoc experiments conducted in the middle 1960s, but those of Troxell's are the most well-documented for fire growth.

*Bracketed numbers refer to references listed on page 28.

4 FIRE TESTING OF PIPE SYSTEMS IN FIRE RESISTANT WALLS

Given a flashed over fire on one side of a fire-resistant wall, what is the influence of a plastic pipe system within the wall? This has been the logical next question which has been addressed in several different experimental programs during the past few years. McGuire [2] exposed 30-in. sections of 10-in. diameter plastic pipe in a special test furnace with two 16-in. square concrete "test walls." The pipe ran horizontally across the furnace and the pipe protruded approximately 3 feet on each side. Each test was regarded as providing two results, since in general, one penetration was sleeved with a 4- to 9-in. steel tube, while the penetration of the other test wall was only packed with a soft asbestos material.

The McGuire test used the ASTM E119 Standard time temperature curve and six types of plastic pipe were exposed. It was usual during the tests for the unsleeved pipe to allow hot gases or flames to issue freely around the pipe in approximately 30 minutes, while the other sleeved end would not show failure for up to 2 hours. Another series of experiments with floor penetrations were "not encouraging" and indicated that the sleeve approach did not work well. Only once when the pipe collapsed did the experiment run to 2 hours without flame penetration.

There have been a number of test programs in which full-scale wood-frame or steel-frame, fire-resistant walls have been exposed in E119 test furnaces. The configuration of the wall specimens is schematically shown in Figure A2, with the fire test furnace shown on one side of the wall and the question marks showing where the fire might spread. The three most recent experimental programs have been conducted at Ohio State University (OSU), the National Bureau of Standards (NBS), and the University of California at Berkeley (UCB). In this section a summary of each of these programs will be presented as well as an overview of their results.

Ohio State University Program

A typical DWV configuration of a wall specimen for the OSU test program is shown in Figure A3. There were 1- and 2-hour walls tested by ASTM E119 Standard in the OSU program, with both ABS and PVC DWV systems installed as shown in Figure A3. The specimens were mounted within the load application test frame, and this precluded evaluation of fire spread

within the wall above or below the fire floor. A short elbow connection above the specimen vented the stacks to the atmosphere, and this allowed some observation of upward fire travel but not to an upper-story penetration as shown in Figure A2. The penetrations of the back-to-back laterals were protected by a commonly available furnace setting cement, as shown by the black patches visible in Figure A3. Five standard test reports describe the details of each test [3], but in summary, all of the assemblies retained their expected fire resistance and there was no excess transmission of heat or any flaming on the unexposed face of the walls. In addition, the 2-hour assemblies retained their load-bearing qualities during the tests.

National Bureau of Standards Program

The NBS program involved 10 separate ASTM E119 wall tests which can be divided into three categories [4]. The first of these categories is a Chase Test where a 1-hour fire wall was built in the furnace frame incorporating four separate plumbing chases containing both metal and plastic DWV systems. The second category of NBS tests consisted of Plumbing Wall tests where the DWV system was placed **completely** within a 1-hour fire-resistive wall, as schematically shown in Figure A2. Finally, the third category of the NBS program can be characterized as Tight-Clearance and Unsealed Experiments where the DWV system was either too large for complete installation in the plumbing wall or holes around the penetrations are larger than necessary and/or unsealed. In general, this latter category involved obviously compromising certain aspects of the fire-resistive wall in order to install the DWV system.

In the following discussion, the 10 NBS experiments will be divided into the three categories listed above. In a few cases, certain portions of the test assembly belonged to different categories and these will be listed separately. In all cases, the NBS test number will be listed, followed by the chase or cavity number.

Chase Tests

There were two chase tests in this series of experiments at NBS. In each test, four 20-in. x 20-in. chases were constructed behind a 16-ft-wide, 10-ft-high wall constructed of 2 by 4 wood studs with 5/8-in. Type X gypsum wallboard. The tests are summarized in Table A1. It should be noted that, although both NBS Tests 1 and 2 had to be stopped before 1 hour, the fire performances of the DWV systems were satisfactory.

Plumbing Wall Tests

There were eight fire tests of walls with DWV systems installed between the faces. Each test wall contained four separate DWV systems in different cavities within the wall and thus each test can be considered as four simultaneous experiments. Tested in this phase of the NBS program were 12 separate DWV cavities which had adequate clearance and adequate sealing around penetrations (these are summarized in Table A2). Four furnace runs are listed in Table A2, with either two or four cavities listed under each run. In general, there are relatively few differences between the individual cavities except for materials and dimensions. Although the NBS Report was not completely consistent, there appeared to be 10 satisfactory performances and one that was not satisfactory. These are noted in Table A2 where the slight excess temperature rise is noted on four of the systems that showed an overall satisfactory performance.

Tight-Clearance and Unsealed Experiments

In almost all experiments, some situations are not generally satisfactory. In the NBS test series a number of DWV systems of both plastic and metal were not satisfactory, and these have been categorized here under the title of Tight-Clearance and Unsealed Experiments. In general, they are not recommended for use in real buildings, but they give valuable insight into potential problems in the field. These experiments are summarized in Table A3, where a short summary of their failings is given. There are 20 cavities in six different runs and all but one were judged unsatisfactory.

University of California, Berkeley, Program

This program was essentially the same as that at OSU and NBS except that the Uniform Plumbing Code was followed for pipe configuration and a more "inspectable" means of protecting the laterals was sought. Seven separate ASTM E119 tests were conducted in the UCB program. These were of the "Plumbing Wall" type described above for the NBS program. The plumbing installations were two-story, dry-vented systems with back-to-back lateral connections through the wall. The plastic materials in the DWV systems have been ABS, PVC, and polypropylene (PP), which represent a wide variation in many properties.

All of the tests in the UCB series were essentially the same and represent typical installations of DWV within a plumbing wall. A vertical section through the test wall and the furnace is shown in Figure A2. As noted above, one of the objectives of the tests was to

evaluate the vertical fire spread potential above and below the fire floor, as well as spread into the adjacent compartment behind the room on fire (i.e., the furnace). These possible fire spread directions are also schematically shown in Figure A2, where it should be noted that the exposed face of the wall is limited to just the portion of the wall specimen representing one story. There were a few differences between each test, but essentially all tests exposed the same kind of plumbing configuration to the same fire situation. The principal differences were in the protection of the plastic pipe. The first two tests used the plaster backpacking technique suggested by the NBS experiments. It was found, however, that those methods should be supplemented by other protection.

The test walls are shown in Figure A4. The basic 1-hour fire-rated wall consisted of 2-in. by 6-in. wood studs 16 in. on center, with one layer of 5/8-in. Type X gypsum wallboard applied vertically on each face. The gypsum wallboard was nailed with 6d dry wall nails 7 in. on center with all edges on nailing members. This wall is listed in the Uniform Building Code as a wall with 1-hour fire resistance (Uniform Building Code, Chapter 43, Number 76) [5].

The plumbing system configuration is shown in Figure A4. Holes through horizontal plates were drilled 1/2 in. larger in diameter than the outer diameter of the 3-in. drain and vent pipes and were **not** backpacked. All penetrations through gypsum wallboard were made 1/2 in. larger in diameter than the outer diameter of the pipe extending through the wallboard and were finished with drywall joint compound. All plumbing assemblies were supported by riser clamps at each floor line on each penetrating pipe. The drain pipes were individually supported and were connected to an actual drain line so that air drawn into the system would simulate a realistic drain line condition. Each P-trap was filled with water and was supported by a unistrut bracket to simulate the support given by a sink.

A number of different methods of protecting the back-to-back penetrations were evaluated in the UCB program, but by far the simplest and most successful technique for ABS or PVC was to nail 18-in.-high steel sheets to both sides of the plumbing cavity at the location of the penetrations. Thus, each plumbing assembly had 18-in.-high by 24-in.-wide 24-gauge galvanized steel sheets surrounding the pipe at each wall surface penetration. A 2-1/4-in. hole was punched 4 in. up from the bottom of the metal sheets, 12 in. from each vertical edge. The pipe-fitting hubs which penetrated the wall surfaces fit snugly through this hole. The metal sheets were nailed to the face of the wood studs with three 8d nails on each stud. These sheets of steel could be easily checked under actual construction conditions at the "rough plumbing" inspection. A photograph, which was taken from the unexposed face before the gypsum wallboard had been installed and which shows the entire wall assembly, is shown in Figure A5(a). The single PVC (white) system is visible on the left of the photograph and the two ABS (black) systems are on the right [6]. Another wall with two PVC and one ABS system was tested at a later time to give a total of six plumbing cavities tested with this method of protection. A close-up photograph of two cavities is shown in Figure A5(b), where the metal sheets are shown at a slightly oblique angle. Note that this symmetrical protection technique does not require backpacking or other operations that would be difficult to inspect in the field.

The tests were conducted in accordance with ASTM E119, and a positive pressure differential was maintained over the upper two-thirds of the exposed region of the test assembly. The pressure gradient was essentially linear, varying from -0.03 in. of water at the bottom of the exposed region, 0.00 at the one-third height, and +0.03 in. of water at two-thirds height. This would extrapolate to +0.06 in. of water at the top of the exposed region.

A photograph of the unexposed face of the wall specimen after the test is shown in Figure A6. Measurements of the temperature rise on the unexposed face of the specimen were made under the 16 square pads shown in Figure A6. There were three thermocouples on the unexposed face of each plumbing cavity in the region subjected to fire exposure, and one thermocouple on the unexposed face of the upper section of each plumbing cavity. In addition, a similar set of four unexposed face thermocouples was placed on a nonplumbing cavity to get comparison values.

The standard ASTM E119 heat transmission criteria are that no one thermocouple on the unexposed surface of the wall may exceed 181°C above ambient temperature and that the average of nine unexposed face thermocouples may not exceed 139°C above ambient. At the end of 1 hour, the back face temperature rises in the exposed region of the specimen (thermocouples 5, 6, and 7) were as follows:

Wall Cavity	Maximum ΔT	Average ΔT
Left plumbing (PVC)	70°C	66°C
Center plumbing (ABS)	90°C	85°C
Right plumbing (ABS)	87°C	79°C
Nonplumbing	91°C	86°C

The temperature rise on the unexposed face of the upper floor portion of the specimen ranged from 44°C to 49°C for the plumbing cavities and was 19°C for the nonplumbing cavity.

For the second test, the corresponding back face temperature rises were as follows:

Wall Cavity	**Maximum ΔT**	**Average ΔT**
Left plumbing (PVC)	91°C	76°C
Center plumbing (PVC)	79°C	70°C
Right plumbing (ABS)	99°C	94°C
Nonplumbing	96°C	96°C

The temperature rise on the unexposed face of the upper floor portion of the specimen ranged from 51°C to 52°C for the plumbing cavities and was 21°C for the nonplumbing cavity. As in the previous test, the unexposed face temperature rises in the exposed region of the specimen were well below the allowable and were either less than or approximately equal to that on the nonplumbing cavity. The sheet steel played an important role in preventing excess temperature rise at the thermocouples (#5) located just above the laterals. That location corresponds to the area under a sink that might be reasonably expected to have combustibles in proximity, and it should be a mandatory location for a temperature measurement in tests such as these.

Photographs of the exposed face of one of the specimens are shown in Figure A7(a) and (b). Figure A7(a) was taken just after the specimen was withdrawn from the furnace, and one can see that the wallboard was still in place. Figure A7(b) shows a close-up of the same specimen after some of the exposed wallboard has been removed. One can see that a plug of molten plastic has formed at the bottom of the cavity to block the fire from going to the floor below. A similar thing happens in the cavity above the fire floor to block the passage of fire above. For ABS and PVC it appears that if the pipe can collapse, it will form a charred plastic mass at the bottom of the cavity which prevents fire from going either up or down inside the wall. There were five plumbing wall tests in the UCB program prior to the two described above, and the importance of collapse of ABS and PVC pipe was evident in each failure as well as the satisfactory performances.

The entire UCB plumbing wall test series is summarized in Table A4 in much the same fashion as the NBS tests. The other tests in the UCB program were essentially the same as those described above, with only the details of the lateral protection being changed.

The first four tests in the Program were summarized by Williamson [7] as follows: (The figure and table numbers have been changed to correspond to this report.)

All of the tests in the UCB series were essentially the same and represent typical installations of DWV within a plumbing wall. A vertical section through the test wall and the furnace is shown in Figure A2. As noted above, one of the objectives of the tests was to evaluate the vertical fire spread potential above and below the fire floor as well as spread into the adjacent compartment behind the room on fire (i.e., the furnace). These possible fire spread directions are schematically shown in Figure A2, where it should be noted that the exposed face of the wall is limited to just the portion of the wall specimen representing one story. A photograph of one of the plumbing assemblies is shown in the gallery at the end of this section. There are a number of photographs of the test walls before and after the fire exposure, as well as photographs of details.

There were a few differences between each test, but essentially all four tests exposed the same kind of plumbing configuration to the same fire situation. The principal differences were in the protection of the plastic pipe. The first two tests utilized the plaster backpacking technique suggested by the NBS experiments. It was found, however, that those methods should be supplemented by other protection. In particular, in the first test the fall-off of the wall-hung lavatories presented a severe problem which resulted in the failure of two of the three plumbing cavities. It should be noted that metal DWV systems would probably experience similar problems, but these have not been tested at this time. The second test was changed to have a simple support bracket and this is shown in a number of photographs. A summary of the tests is shown in Table A4 in much the same fashion as the NBS tests (above).

There have been a total of twelve cavities tested, and there have been seven satisfactory performances and five failures. This does not take into account a number of cavities that were performing well in the third test until extensive quantities of GWB fell off on the exposed side of the assembly. This fall-off was judged unrelated to the plastic plumbing and, thus, those cavities have been discounted. The fall-off of the lavatories in the first test was judged to be related to plumbing chase performances and these results have been included in Table A4. The unexposed face temperature measurements for the four tests are attached in an annex to this report.* The location of each thermocouple is noted in Figure A4.

The summary from the NBS report, reproduced above, is completely consistent with the UCB tests. Plastic DWV systems can be installed in fire-rated walls without the loss of a rating. The traditional approach has been to let the failures go unpublished while the successes go forward as the recommended practice. This has generally left the code officials in the dark about what details are important. The OSU, NBS and UCB fire tests show a knowledgeable code official the general

*These have not been included here.

methods of maintaining the fire resistance of walls, and a set of detailed methods specific to ABS, PP and PVC will be present in the final report of the UCB fire tests. In the meantime, the UCB tests have illustrated that ABS needs some space to collapse to block the openings in the exposed and unexposed portion of the assembly. The PP system shows good performance when the four-foot mineral wool batts fill the lower portion of each chase. Finally, the PVC system shows good performance when either it is allowed to collapse, or it is insulated with mineral wool. For simplicity and ease of inspection, there will be a continued effort in the UCB test program to find the same technique to render both ABS and PVC DWV systems safe. There will be a strong emphasis on choosing methods that can be inspected prior to the installation of GWB and which are intrinsically fire safe. This will include a demonstrated ability to pass the fire test with wall-mounted lavatories. The expert observer can see from the NBS and UCB tests that there are a number of combinations that will meet this objective.

It is interesting to speculate how the typical metal DWV system will perform when a wall-mounted lavatory falls away in the test furnace. The mineral wool systems tested in UCB Test No. 4 would appear to offer substantial protection for the plastic systems from this problem. It may be important that all DWV systems installed in rated walls be protected by tested methods.

The sheet metal protection method answered the need for a simple, easily inspectable method of protection. It should be noted that 21 separate plumbing chases were evaluated in the UCB program, and the sheet metal method of protection was tested three times for both ABS and PVC to see if it worked consistently. Further discussion of these tests is below.

Other Wall Tests

A number of other fire test programs have been reviewed and implicitly considered in this report. A complete list of these is given in the Annex.

Overview of OSU, NBS, and UCB Programs

Given a flashed-over fire on one side of a fire-resistant wall, what is the influence of a plastic DWV system within the wall? The OSU, NBS, and UCB test programs indicate that fire resistance will not be reduced, provided some care has been exercised in installing the DWV system. A number of methods of protection were evaluated in these test programs, but it is instructive to make a histogram of the failure times for the three test programs without regard for the particular test details. Such a histogram is shown in Figure A8(a), where either the thermal transmission or the flame-through criteria are given for the NBS experiments summarized in Table A2 and 12 of the UCB wall cavities summarized in Table A4 (specifically tests 1, 2, 4, and 5). Figure A8(b) shows an extension of this data which gives the probability of successful performance of the plumbing cavities represented in the two test programs. This probability is obtained by taking the cumulative distribution frequence (CDF) of the histogram shown in Figure A8(a) and subtracting it from one. The tests shown in Figure A8 were all conducted on wall cavities that were nominally 1 hour fire resistive; the plastic pipe was installed within the wall with only laterals penetrating the outer surfaces. The probability that any plumbing cavity in a 1-hour wall would last at least 30 minutes is better than 95 percent according to Figure A8(b). Thus, the designer can assume that even if the specified method of protection (such as the metal shields shown in Figure A5) is left out, the fire resistance of the wall is not changed by more than a factor of two.

There will be further discussion of fire test of plumbing walls below, but it is important to make the point here that the OSU, NBS, and UCB test programs taken together allow certain conclusions: Undoubtedly new methods will be developed in the future which will have to be tested, but, in general, sufficient information is now available for plastic DWV systems to be used within fire resistant walls. The use of plastic DWV pipe can thus be justified in those buildings where it will be primarily installed in walls. This is a relatively large category of buildings which include five- or six-story office and apartment buildings, numerous industrial buildings, and other buildings such as motels, dormitories, hospitals, nursing homes, and other low-rise structures.

It should be noted that the threat of toxic gases and smoke production was qualitatively evaluated in all of the test programs, and there were no findings of unsatisfactory smoke penetration of the fire-resistant walls and no hazard was identified that would preclude the use of plastic DWV systems on the basis of a toxic threat.

5 FIRE TESTING OF PIPE SYSTEMS IN FIRE-RESISTANT FLOOR AND CEILING ASSEMBLIES

Given a flashed over fire above or below a fire-resistant floor and ceiling assembly, what is the influence of a plastic pipe system within the assembly or passing through it? This question is essentially the same as that

addressed in the previous section for walls, but it is generally more difficult to fire test floor and ceiling assemblies and there are fewer experimental studies at this time. Several aspects of the floor and ceiling assembly do not appear with walls, such as the occurrence of large "plenum" spaces between floors and suspended ceilings where large quantities of pipe may serve the floor above. Sometimes these plenum spaces are used for "return air" in the ventilation system and this further complicates the evaluation of combustible materials in these concealed spaces.

The Ohio State University program discussed in section 4, above, included one test of a floor and ceiling assembly containing plastic pipe [9], and it is instructive to describe this experiment in detail. Another test series that included four separate experiments of pipe systems penetrating concrete floors was conducted at the Australian fire test laboratory [10] and this series will also be described in detail.

Ohio State Floor and Ceiling Test – May 1974

On December 13, 1973, the Building Research Laboratory of the Ohio State University conducted an ASTM E119 Test on a floor and ceiling assembly containing both ABS and PVC DWV plumbing systems [9]. The assembly was constructed of 10 J2 open web steel joists, a 2 1/2-in.-thick concrete deck on metal lath with an exposed grid system supporting 24-in.-wide by 38-in.-long by 5/8-in.-thick lay-in ceiling tile and light fixtures as shown in Figure A9. The two separate plumbing systems were placed in opposite quadrants of the assembly within the plenum cavity between the floor and the suspended ceiling as shown in Figures A9 and A10. In addition, wall stubs extended above and below the assembly as shown in detail in Figure A11. The top surface of the assembly thus had four partial wall assemblies protruding 6 feet above floor level and two waste closets (toilets) were installed as shown in Figure A12 to complete the unexposed face of the assembly.

The concrete test frame was assembled to form a 16 ft 2 3/4 in. by 14 ft 2 3/4 in. opening for the test assembly. Steel ledge angles measuring 8 in. by 4 in. were attached to hanger plates across each 16 ft 2 3/4 in. side of the frame to form the end supports for the steel joists. The joists were placed 24 in. on center with the end bearings on the ledge angles an average of 3 in. and welded to the ledge angles with welds averaging 1 in. in length. The 1/2-in.-diameter bridging bars were welded to both the top and bottom chords of the steel joists at midspan. The 3/8-in. rib lath was attached perpendicular to the joists and was tied with No. 18 gauge tie wire 8 in. on center at the side lap of the selvage and at every other 3/8-in. rib at the joists. The end lath laps measured approximately 3 5/8 in.

The concrete slab measuring 2 1/2 in. thick over the top of the bar joist was placed over the lath. The sag in the metal lath between the open web steel joists due to the concrete placement ranged from 3/4 in. to 2 3/4 in. and averaged 1 3/8 in. The PVC and ABS plumbing runs were inserted through the bar joists. A 3-ft. vertical wall was built on the exposed surface around the PVC and ABS vent pipes. Figure A13 shows the PVC area of the assembly at this stage of construction, and the ABS area was essentially the same.

A superimposed load of 2310 lb per joist was applied to the assembly at the start of the test and maintained throughout the test. This load, in addition to the dead load of 1422.5 lb per joist, constituted a total load calculated to impose a design allowable bending movement of 70 in. kips in the joists.

The concrete test frame containing the floor and ceiling assembly was placed in the restraining frame of the furnace. The loading frame was placed over the specimen and securely bolted to the restraining frame. Eight interconnected hydraulic rams were fastened vertically to the loading frame and positioned so as to properly apply the load. The loading system was monitored continuously throughout the test to insure a constant superimposed load.

The unexposed surface temperature was measured with 10 Chromel-Alumel thermocouples. Each thermocouple was tightly covered with an oven-dried, flexible, felted asbestos pad 6 in. square by 0.4 in. thick. One thermocouple was located near the center of the specimen and one was located near the center of the quarter sections. The other five thermocouples were located to provide representative readings with respect to the construction. The locations of unexposed surface thermocouples are shown in Figure A14. Note that the unexposed thermocouples were all flush with the floor and none were placed near the waste closet or the stub walls.

The observations recorded during the test were divided into those on the "exposed surface" (i.e., inside the furnace) and those on the "unexposed surface" which was the floor with the two waste closets and stub walls. These observations have been reproduced here exactly as they are reported in the test report [9], since it is instructive to review them with reference to the plastic pipe.

Exposed Surface Observations

1 minute:	The southeast end filler panel had lifted at the edge.
2 minutes:	The tile began to darken and paint began to char on the metal.
3 minutes:	The whole surface had darkened. The expansion joints had functioned. The expansion joints all lifted upwards, with the center expansion lifting more than the other two.
5 minutes:	The surface began to lighten. The wallboard paper on the wall stubs had charred.
10 minutes:	The joint treatment had cracked and loosened.
13 minutes:	The south light ballast cover fell. Smoke issued through the north ballast cover.
14 minutes:	Black "goop" oozed out of the south ballast. The north ballast cover fell.
36 minutes:	Flames with dark smoke issued from the northeast quadrant where the ABS pipe run was located.
39 minutes:	The east end of the center east tile sagged below the grid.
40 minutes:	Smoking started in the southwest quadrant where the PVC pipe run was. The configuration of the pipe run was outlined darkly in the northeast area accompanied by heavy smoking.
44 minutes:	The metal grid and fixtures glowed red.
60 minutes:	Figure A15 shows the exposed surface at this time.
70 minutes:	The cross tee southwest of center tilted.
71 minutes:	Flaming continued on the northeast area.
79 minutes:	The end of the east center tile was 1 in. below the grid.
89 minutes:	The tile southwest of center had sagged 1 in. below the grid along the long edge.
93 minutes:	The center east tile sagged 3 in. at the end.
96 minutes:	The center west tile fell.
100 minutes:	The center east tile fell.
105 minutes:	The tile north of the fallen tile on the west side fell.
107 minutes:	Profuse flaming issued at the base of the wall stubs.
112 minutes:	The test was terminated.

Unexposed Surface Observations

0 minutes:	A superimposed load of 2310 lb per joist was applied to the assembly without any apparent distress.
2 minutes:	Smoke mixed with steam issued from the periphery of the specimen.
3 minutes:	Smoke mixed with steam issued from all the plumbing risers.
4 minutes:	Heavy smoke emission from the periphery of the specimen made observations very difficult.
15 minutes:	The smoke emission decreased significantly.
45 minutes:	Smoke mixed with steam issued from the periphery, the vent risers, and around the plumbing fixtures. Diagonal cracks had formed in all four corners of the slab.
70 minutes:	Hairline cracks had formed in the surface of the slab at several locations.
98 minutes:	The stud chase in the center PVC wall was filled with smoke. Longitudinal cracks had formed in the slab between load points.
105 minutes:	The stud chase in the center ABS wall was filled with smoke. Smoke issued from around the bottom of both center walls. The deflection of the assembly was noticeable.
107 minutes:	Cracking sounds were heard from the assembly.
112 minutes:	Thermocouple No. 19 exceeded the allowable single high temperature of 411°F at this time.

The temperature and time data from the furnace and the unexposed thermocouples are given in Figure

A16. The ambient or room temperature was measured at 72°F before the test, so all readings in Figure A16 should have 72° subtracted from them to be converted to temperature rise. The temperature and time data from the supplementary thermocouples 37 through 43 are shown in Figure A17. The locations of all the thermocouples are shown in Figure A14.

The test report [9] did not attempt to analyze the result beyond the 112-minute high temperature failure at *location 19* (as shown in Figure A14). The pressure in the furnace was not given in the report and there were no photographs from the unexposed side after the test. There were no explanations of what happened to the pipe within the stub walls during or after the test and there were only passing observations concerning smoke on the unexposed surfaces. There will be a discussion of this test below and the author's conclusions from the test will be given.

Australian Floor Tests – 1975-76

The Experimental Building Station staff made "a study of the extent to which the passage of soil and waste pipes through concrete floor slabs reduces the potential fire resistance of the floor slab." [10] In the following description, the terminology and units of measure of the Australian researchers will be used. The test specimen consisted of an inverted concrete box 1.12 m (3.64 ft) square and 0.54 m (1.76 ft) deep which was placed on a gas-fired pilot furnace and subjected to the Australian Standard No. 1530, which is equivalent to the ASTM E119. The concrete was approximately 13 cm (5.2 in.) thick and the same box was used for all experiments. The concrete box had an estimated initial fire resistance of 2 hours.

For each experiment, a variety of pipes was passed through holes in the top of the box and these were supported above the box by a light steel framework. The pipes were grouted in position in the slab with a cement-sand grout. There were four experiments in which the types and geometries of the pipe were varied. In the following summary, the details and the observations from each experiment will be described.

Experiment No. 1 (conducted on May 26, 1975)

Description of Specimen. The specimen as examined consisted of three main components: a section of concrete floor slab, a number of plastic pipes, and a lightweight steel framework supporting the pipes. The assembly is shown in Figures A8 and A9. Nine holes were located in the floor section, and one hole was provided in one vertical side. The holes were tapered inward, and were designed to provide approximately 5 mm minimum clearance all around the pipes. The holes were arranged in a grid system with rows designated A, B, and C in one direction and 1, 2, and 3 in the other. Of the ten pipes, seven were PVC, two were polypropylene, and one was ABS. The pipe ranged in size from 10 cm to 2.5 cm (4 in. to 1 in.), and two of the PVC pipes were actually identified as "conduit," but there was no indication that they contained wire.

Installation of Pipes. Each pipe was cut to an approximate length of 60 cm (2 ft). The portions of the pipes to be grouted were coated with 3:1 sand-cement grout. They protruded approximately 15 cm (6 in.) into the box. Certain pipes were jointed inside the box enclosure with various fittings shown in Figure A19. The pipes were extended to a height of approximately 3 m (10 ft) above the concrete box and supported by pipe clamps to a steel framework shown in Figure A18.

Experimental Observations. At 3 minutes into the test, it was noted that the PVC pipes showed "some softening" above the concrete box. At the same time heavy acrid smoke issued from the open top ends of the pipes and from the furnace flues. At 5 minutes, some of the pipe had actually buckled above the concrete box. At 10 minutes, the softening of the pipes had "progressed" in general, and in particular at location *A1*, a *10-cm (4-in.) PVC pipe "burned through at* the level of the upper surface of the concrete box and smoke issued through the opening so formed." "The smoke subsided at 20 minutes" and "at 30 minutes most pipes were burned through just above the concrete slab." Then after the furnace burners were extinguished at 62 minutes, "considerable flaming was observed," presumably inside the furnace. The photograph shown in Figure A20 was taken at the conclusion of the test and it is noted that the softened and collapsed pipes are illustrated.

Unexposed Temperatures. The maximum allowable temperature rise of 180°C (325°F) above the initial temperature was not reached on the unexposed surface of the slab section of the concrete box away from the pipe penetrations, but was reached on the top of a grouted section at 33 minutes, and on the external wall of one of the PVC pipes at 12 minutes into the test.

Experiment No. 2 (conducted on July 21, 1975)

Description of Specimen. The specimen examined consisted of the same three basic components as in Experiment No. 1. The concrete box enclosure and the steel supporting framework were reused, with some

modifications. Seven holes were enlarged and three were plugged with grout. Another hole was cut in the side wall.

Installation of pipes. Four PVC pipes, two cast-iron pipes, and two copper pipes were installed. The pipes were cut to an approximate length of 60 cm (2 ft), and 13-cm- (5-in.-) long plastic sleeves were fitted over the plastic pipes approximately 15 cm (6 in.) from their lower ends. The sleeves were coated with solvent cement and dusted with sand. The pipes were then set into the box enclosure with 5:1 sand-cement grout. They protruded approximately 15 cm (6 in.) below the soffit of the floor slab. The addition of the plastic sleeves practically doubled the thickness of the plastic pipes in the particular locations. The bottom and top ends of all pipes were left open. The box was then placed on top of the pilot furnace, and the steel supporting framework was placed over the box. All pipes extended to a height of approximately 3 m (10 ft) above the box enclosure.

Experimental Observations. At 3 minutes into the test, the PVC pipes started to buckle and smoke began to issue from their open ends. It was noted at 8 minutes that the copper pipes had significant discoloration, which was confirmed by temperature measurements to be due to high temperature. The smoke issuing from the tops of the PVC pipes is evident in Figure A21, which shows the experiment at 15 minutes into the test. Some softening of the PVC pipe is visible in Figure A21. At 17 minutes, one of the PVC pipes burned through at the elbow connection into the side of the concrete box (location A0), and smoke began to issue through the crack. At 23 minutes, the PVC pipe at location A1 burned through, slipped from the top fixing, and fell across the box. Copious quantities of smoke started to issue through the opening. At 25 minutes, all PVC pipes burned through. At 30 minutes, a photograph (Figure A22) was taken; it shows the displaced pipe and bend fitting with charred products of combustion partially blocking the opening, and smoke issuing through the hole. At 40 minutes, the tape used for the attachment of thermocouples to the external walls of the pipes ignited and burned at one location. The test was terminated at 55 minutes, and Figure A23 shows the appearance of the specimen after the test.

Unexposed Temperatures. The maximum allowable temperature rise of 180°C (325°F) above the initial temperature was not reached on the unexposed surface of the slab section of the concrete box away from the pipe penetrations, but this temperature limit was reached on the top of the grouted sections adjacent to the metal and PVC pipes at 9 minutes and at 26 minutes, respectively. The maximum temperature rise on the external walls of the metal pipes was exceeded in 2 minutes and on PVC pipes in 16 minutes.

Experiment No. 3 (conducted on August 15, 1975)

Description of the Specimen. The concrete box was reused from the previous experiments with the side holes sealed with grout.

Installation of Pipes. The test had four cast iron pipes and two copper pipes. Their bottom ends were sealed and were considered to simulate continuous metal piping passing through the fire compartment.

Experimental Observations. The metal pipes remained stable throughout the 62-minute test.

Unexposed Temperatures. The maximum allowable temperature rise of 180°C (325°F) above the initial temperature was exceeded at 27 minutes and 44 minutes, as measured by the thermocouples located 50 mm above the concrete box enclosure on the two copper pipes, and at 56 minutes on one of the cast iron pipes.

Experiment No. 4 (conducted on September 15, 1975)

Description of the Specimen. The concrete box was reused from the previous experiments. The steel framework was modified to support the pipes approximately 2 ft above the top of the concrete box.

Installation of Pipes. Five 11-cm (4-in.) O.D. PVC pipes were fitted into the concrete box with special sleeve fittings. The pipes were approximately 1.5 m long and each was grouted into the slab section of the box enclosure with "ciment fondu" so that it protruded into the box enclosure approximately 150 mm. The pipes were supported at mid-height by pipe brackets attached to the steel framework. The sleeve fittings were arranged as follows:

Sleeve fitting 1 comprised a PVC sleeve and an insulating infill. The sleeve was 220 mm O.D. x 195 mm I.D. PVC pipe, 300 mm long. A 315-mm O.D., 10-mm-thick PVC flange was cemented to the sleeve, and then the sleeve assembly was cut into two semi-cylindrical sections. The infill was Bradford Rockwool pipe insulation 187 mm O.D. x 113 mm I.D. x 300 mm long. The density of the insulation was measured to be 200 kg/m^3. A 12-mm-deep x 50-mm-high annular groove was cut inside the infill 75 mm below the top. The two halves of the infill were then placed around a

grouted plastic pipe on top of the box enclosure. The two halves of the sleeve were placed over the Rockwool insulation, and jointed together with two worm-type clamps. The sleeve was then screwed with four screws through its flange to plugs inserted in the concrete of the slab section.

Sleeve fitting 2 was similar to sleeve fitting 1, except that the annular groove was not formed in the infill.

Sleeve fitting 3 was similar to sleeve fitting 1, except that the height of the fitting was 150 mm, and the annular groove was 12 mm deep x 25 mm high and was cut 50 mm below the top of the fitting.

Sleeve fitting 4 was similar to sleeve fitting 3, except that the annular groove was not formed in the infill.

Sleeve fitting 5 was similar to sleeve fitting 1, except that 65 mm were cut from the top of the infill; the gap so formed was filled with gypsum plaster, and the annular groove was cut 75 mm below the top of the fitting.

Experimental Observations. At 3 minutes from commencement of the examination, the pipe above sleeve fitting 4 (short fitting without a groove) bent above the fixing bracket and dropped onto the supporting frame. This is shown in Figure A24 where it is evident that the pipe crimped at the bend, and the blockage reduced the flow of gases through the pipe. At 5 minutes, the same behavior occurred with the pipe above sleeve fitting 2 (long fitting without groove). At 12 minutes, all the pipes commenced to bend above the fixing clips. The flow of gases from the open ends of the bent pipes, although reduced, still continued. Figure A25 shows the experiment after 32 minutes, and it is evident that all of the pipes have collapsed onto the support framework and that smoke is issuing from several of them. It was noted, however, that at the time Figure A25 was made, there were no holes burned through the pipes or sleeve fittings. The burning started soon afterwards and at 35 minutes, the pipe above sleeve fitting 3 charred. A hole was visible in this pipe at 45 minutes. At the same time is was also observed that the pipe above sleeve fitting 5 sealed itself at the bend, and the flow of gases through its open end stopped completely. At 58 minutes, another inspection was made, which revealed that no holes were burned through any pipe, except the pipe above sleeve fitting 3. The examination terminated at 1 hour and 2 minutes from commencement of the test. One minute later, the furnace was extinguished. Air flow was maintained, and the pipe above sleeve fitting 3 ignited. Four minutes later the pipe above sleeve fitting 1 ignited also.

Subsequent Inspection. An inspection of the pipes was made the next day.

Pipe and sleeve fitting 1. The pipe was burned approximately 80 mm above the top of the sleeve fitting, and the plastic sleeve component and the insulation were severely damaged. Char had formed inside the sleeve fitting but did not plug the opening.

Pipe and sleeve fitting 2. The plastic sleeve component was burned less than on sleeve fitting 1. There was considerable charring inside the sleeve fitting, and it was estimated that the opening was reduced by 50 percent thereby.

Pipe and sleeve fitting 3. The pipe burned above the sleeve fitting component, and the insulation was excessively damaged.

Pipe and sleeve fitting 4. The pipe burned above the sleeve fitting. The plastic sleeve component and the insulation were severely damaged. Considerable charring occurred inside the sleeve fitting.

Pipe and sleeve fitting 5. The pipe above the plastic sleeve component was not perforated, and the sleeve fitting was relatively undamaged. Considerable charring had occurred inside the sleeve fitting.

Summary of Subsequent Inspection. It appears that the burning and charring inside the sleeve fittings continued long after the furnace was extinguished and the air flow stopped. Pools of strong acid (believed to be hydrochloric acid) were discovered on the top surface of the concrete box enclosure 24 hours after the examination was concluded. It was suspected that the damage to the insulation inside the sleeve fittings was caused by distilling hydrochloric acid. The annular groove on the inside diameter of the insulation infill appeared to act to prevent the formation of char inside the sleeve fitting. The ring of gypsum plaster on top of sleeve fitting 5 maintained the temperature on the pipe above it at temperatures below-melting point. Formation of additional char was probably prevented by the annular ring, with the detrimental effect noted above.

Australian Research Conclusions

The initial conclusions of the Australian research team are as follows.

Unprotected PVC Pipes. It was evident from the reported examinations that unprotected PVC soil, waste,

and vent pipes could burn due to building fires, leaving unprotected holes through which heat and flames could pass. Additionally, the copious quantities of smoke and fumes may constitute a danger to the occupants of a building soon after the commencement of fire in one of its compartments.* A complete gas analysis of fumes was not carried out, but the concentration of hydrochloric acid was assessed at intervals throughout the first and second examination by using "Drager-Tube" gas analysis, to be approximately 10 to 20 ppm as measured in the general area of the specimen, and more than 100 ppm in the plume of smoke.

PVC Pipes Protected With Sleeve Fittings. The test conducted on 15 September 1975 indicated that all five different sleeve fittings examined maintained the fire resistance of the construction for the first 30 minutes and that some were effective for 60 minutes. The examinations suggest that sleeve fittings can be designed to protect openings formed for the passage of PVC pipes through fire-resisting floors and walls. The development of such fittings should establish their satisfactory performance not only for cases where collapse of the pipe effects a seal and prevents the passage of gases through the pipe, but also for cases where the pipe is so supported beyond the opening that this collapse mechanism cannot occur.

Metal Pipes. From the second test, it was evident that metal pipes with their open lower ends exposed to the furnace conducted enough heat from a fire to raise the temperature of their walls above the fire-rated slab to levels in excess of the criteria for thermal insulation specified in AS 1530 Part 4-1975, Fire-resistance Test of Structures. Some of the pipes with the lower ends open to the seat of fire failed to satisfy the insulation criteria of the above code after 2 minutes from commencement of the test. The pipes with the lower ends closed exceeded the allowable temperature rise shortly before 30 minutes in the test.

The Australian research team makes the following statement:

> **The results of these examinations of approximately 1-hour duration lead to the following conclusions:**
>
> **(i) The unprotected PVC pipes would burn, and if their upper ends are open, they would act as flues discharging products of combustion from the fire-involved storey or compartment.**
>
> **(ii) If certain lengths of the PVC pipes immediately past their penetration through the fire-rated slab were protected with special sleeve fittings, the fire-resisting properties of the penetrated element of structure are likely to be maintained for periods of time dependent on the design of the sleeve fitting.**
>
> **(iii) The unprotected metal pipes will not be penetrated or damaged structurally by the fire. However, these pipes may become so hot as to exceed allowable temperature rise on the unexposed side to the fire side within 30 minutes.**
>
> **(iv) The investigations covered certain aspects only of the performance under the conditions of the standard fire-resistance test of PVC pipe installations that penetrate fire-rated elements of horizontal construction. Wider applicability of the findings is yet to be established.**

There have been a number of other experiments conducted on plastic pipe penetrations of horizontal building elements. McGuire [2] discussed some experiments he conducted, but his fire exposures for the vertical pipe were not as severe as an E119 exposure. McGuire did observe some pipe collapsed to form a seal. There are several tests listed in the Annex which involve plastic pipe penetrations of floors, but the OSU and the Australian research illustrate the principal effects.

Overview of Pipe Systems in Floor and Ceilings

If a plastic pipe system is contained within a wall above the floor and/or below the floor, it is apparent from the tests described above that there is not going to be a fire spread problem. On the other hand, when substantial quantities of plastic pipe are contained in the plenum space between a suspended ceiling and the floor above, there may be a reduction in fire resistance of the whole assembly. The single OSU test gave a slightly reduced fire endurance (112 minutes is 8 minutes short of the 2-hour rating of the assembly), but the high temperature failure was in a quadrant of the test assembly which did not have plumbing installed as shown in Figure A14. It would have been more informative if the OSU test had been continued until more failures occurred.

On the question of smoke, the comments in the OSU observation sheet about smoke at 13 and 14 minutes were probably due to the ballasts, and the smoke from the pipe was not apparent until 36 minutes. Note that on the unexposed face the smoke decreased significantly after 15 minutes, and it is not mentioned again until 45 minutes into the test. In general, when plastic pipe is enclosed within the assembly, there is a delay of approximately 30 minutes before it begins to smoke. The comments about smoke leaving the

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***A comment on this point: The open vent pipes of a DWV pipe system do note terminate inside the building, so this smoke would not be released inside the building.**

open vent pipes have to be interpreted in light of there usually not being open vents within the building. Drain lines are trapped and water lines have valves installed, so there would not be a release of combustion products under normal circumstances.

6 CONCLUSIONS AND RECOMMENDATIONS

One can draw three types of conclusions from the fire tests described in this appendix. First, specific uses of plastic pipe have been shown to be safe. Second, certain aspects of fire tests of plastic pipe are important in interpreting their results; and finally, a number of plastic pipe configurations have not been shown to be safe.

The specific uses of plastic pipe which have been shown to be safe are given in the following subsections. The supporting test information will be referenced from the earlier sections of this appendix.

Plastic Pipe Systems for One- and Two-Family Housing

The installation of DWV systems in one- and two-family housing has been widespread for many years. This dates back in some areas of the United States to the early 1950s, and there has generally been little or no problem from a fire standpoint. The research on fire growth by Troxell was influential in the acceptance of plastic DWV systems in this kind of construction.

Specifically, Troxell showed that plastic pipe installed in the walls did not contribute to fire growth in the adjacent fire room. Since one- and two-family houses are generally unrated, there was no question that the fire resistance was reduced, but it is interesting to note his words about collapsing pipe covering the holes in the plate.

It is the author's conclusion that there is no fire problem associated with plastic DWV systems in one- and two-family housing. The use of plastic pipe for domestic water would also pose no fire problem in these occupancies.

ABS and PVC Plastic Pipe Systems in Fire-Resistant Walls

The fire tests showed that in general, plastic pipe did not reduce the fire resistance of walls in which it was installed. There are certain methods, however, which the author feels are more dependable and safe and these will be recommended.

The simplest and most successful technique for ABS or PVC was to nail 18-in.-high steel sheets to both sides of the plumbing cavity at the location of the penetrations. Thus, each plumbing assembly had 18-in.-high by 24-in.-wide, 24-gauge galvanized steel sheets surrounding the pipe at each wall surface penetration. A 2 1/4-in. hole was punched 4 in. up from the bottom of the metal sheets, 12 in. from each vertical edge. The pipe fitting hubs which penetrated the wall surfaces fit snugly through this hole. The metal sheets were nailed to the face of the wood studs with three 8d nails on each stud. These sheets of steel could be easily checked under actual construction conditions at the "rough plumbing" inspection. A photograph, which was taken from the unexposed face before the gypsum wallboard had been installed and which shows the entire wall assembly, is shown in Figure A5(a). The single PVC (white) system is visible on the left of the photograph, and the two ABS (black) systems are on the right. Another wall with two PVC and one ABS system was tested at a later time to give a total of six plumbing cavities tested with this method of protection. A close-up photograph of two cavities is shown in Figure A5(b), where the metal sheets are shown at a slightly oblique angle. Note that this is a symmetrical protection technique that does not require backpacking or other operations that would be difficult to inspect in the field.

The PP system shows good performance when the 4-ft mineral wool batts fill the lower portion of each chase. Thus, this material which has a much lower viscosity after it has been melted than either ABS or PVC, shows a different behavior. In addition, it should be pointed out that the PP in the UCB tests was the R. and G. Sloane material which is fire-retarded. The mechanism for PP is that it melts and diffuses through the mineral wool, where it simply burns off later in the fire much like a binder in the mineral wool.

It would appear that plastic hot and cold domestic water piping can be installed with the same protection techniques as the plastic DWV piping. It should be noted that the ABS, PVC, or CPVC pipe should be installed so that it collapses within the wall. On the other hand, polyolefine pipe should be protected with mineral wool or fiber glass insulation behind penetrations.

Installation of Plastic Pipe in Fire-Resistant Assemblies Other than Walls

It is obvious that although some tests have been conducted, there is not a general solution to the prob-

lem. The tests show, however, that it is possible to install plastic pipe in fire-resistant floors, floor and ceiling assemblies, and similar elements, but each case would have to be specifically tested.

Installation of Plastic Pipe in Fire-Resistant Buildings

It is obvious that in any real building, the plastic pipe cannot be installed completely in walls or other fire-tested configurations. The total fuel load represented by the plumbing system is only a small fraction of that expected in the structure and content of an actual building, but there are certain locations where the system is gathered together, such as in the basement or in a pipe chase, where substantial quantities of plastic DWV pipe needs special care. It is the author's opinion that this problem can be eliminated by requiring that plastic pipe be installed with a thermal barrier protecting it from the interior of the building. A suggestion for code language is as follows:

> Exposed plastic pipe installed in the interior of all buildings (except Type V-N) shall comply with the flame spread classificaton as set forth in Chapter 42.* In lieu of this requirement, it may be enclosed with a thermal barrier of 1/2-in. gypsum wallboard having a finish rating of not less than 15 minutes, or other approved material having an equivalent finish rating as determined by ASTM E119. Thermal barriers shall be installed in a manner that will remain in place for a minimum of 15 minutes under the same test conditions.

Then as an additional change,

> Vertical pipe chases that pass through more than two floors would be required to have the same flame spread as vertical exit ways.

Thus, the final conclusion is that plastic pipe systems can be safely installed in all fire-resistant buildings. Methods are available that will assure safe installation in the field, and test methods are available to assure that the fire resistance of a structural element will not be reduced by the penetration of plastic pipe. It is understood, however, that if a fire-resistant element, such as a wall or floor/ceiling assembly, is substantially different from those already tested, it must be subjected to tests with plastic pipe installed. It is the author's opinion that there is no reason today to restrict the use of plastic pipe from any type of building, provided the installation is in accordance with the practice described above.

Certain aspects of fire tests are important in interpreting the results. For fire resistance tests such as the OSU, NBS, UCB, and Australian tests described previously, the plastic pipe passes through and/or is contained within a fire-resistant assembly. The exact details of the pipe penetration are important and they should be clearly described in the test report. It is important that the pressure profile in the furnace represent that expected under actual fire conditions. This means a positive pressure in the upper half of the furnace and a neutral plane at approximately one-third height of the wall. The wall tests at OSU, NBS, and UCB all maintained a positive pressure in the upper part of the furnace. It is the author's opinion that the ASTM E119 test should have the following paragraphs:

> The pressure difference between the exterior and interior of the furnace shall be measured at not less than four locations within the furnace. The results are to be documented in the test report in a manner similar to the furnace temperatures.
>
> When testing is to be conducted to evaluate the effects of penetrations in a fire-resistive construction, then the furnace shall be maintained at a positive pressure as follows: for floor, or floor-ceiling assemblies, a pressure of .08 inches at a level of 5 inches below the assembly. For wall assemblies, a pressure of 0.0 inches at 1/3 height and a pressure of .04 inches at a level of the top of the wall assembly.

At this time, it is apparently impossible to operate any floor furnace in the United States with the positive pressure, but McGuire [11] has recently described a flue design which would produce a positive pressure in a floor furnace.

Several plastic pipe configurations have not been shown to be safe, and it is important to indicate some of these. First, any large quantity of exposed plastic pipe is probably not safe. As indicated previously, this would include basements and pipe chases where plumbing from a large building is gathered together. Full-scale experiments might be conducted on exposed plastic pipe to determine if certain breakaway pipe hangers or other devices would allow the pipe to fall to the floor where it would not contribute as much to fire spread. Another unproven use of plastic pipe is an extensive

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*Chapter 42 is the appropriate chapter of the Uniform Building Code, but other codes have comparable chapters. Type V-N is the UBC designation for non-rated combustible construction.

plumbing wall such as that between dormitory restrooms. The OSU, NBS, and UCB wall tests contained relatively isolated plumbing cavities which do not duplicate the plumbing wall configuration.

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   (c) Project 5560, January, 1974, 2 hr. loadbearing wall with ABS DWV.

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Table A1
NBS Chase Tests

NBS Test No.	Construction	Chase No.	Stack	Lateral	Fire Performance
1	20" x 20" chases 2 x 4" wood studs 5/8" X-GWB on both faces All pipe penetrations sealed with plaster spackling compound	1	4" PVC	1½" PVC	Satisfactory
		2	4" PVC	1½" PVC/steel sleeve	Satisfactory
		3	4" PVC	1½" Galvanized steel	Satisfactory
		4	4" PVC	None	Satisfactory
2	20" x 20" chases 2 x 4" wood studs 5/8" X-GWB on one face All pipe penetrations sealed with plaster spackling compound	1	4" PVC	1½" PVC	Satisfactory
		2	4" PVC Hubless	1½" PVC/steel sleeve	Satisfactory
		3	4" Cast Iron Hubless	1½" PVC	Satisfactory
		4	4" Cast Iron	1½" Galvanized iron	Satisfactory

Table A2
NBS Plumbing Wall Tests

NBS Test No.	Construction	Cavity No.	Stack	Lateral	Fire Performance
4	2 x 6" wood stud 5½" cavity 5/8" X-GWB on both faces All pipe penetrations sealed with plaster spackling compound	1	2" PVC	1½" PVC	Satisfactory
		2	2" Copper	1½" Copper	Satisfactory (except for excessive temperature rise at 41 min.–judged not a severe condition. See Figure 28 of NBS Building Sciences Report 72, September 1975, for temperature plot)
		3	2" ABS	1½" ABS	Satisfactory
		4	2" Iron	1½" Iron	Satisfactory
5	Double row of 2 x 4" wood studs 9½" cavity 5/8" X-GWB on both faces All pipe penetrations sealed with plaster spackling compound	2	4" Copper	1½" Copper	Satisfactory (except for excessive temperature rise at 55 min. judged not severe)
		4	4" Cast iron	1½" Galvanized iron	Satisfactory
		1,3	(A 4" hub penetrated the GWB–see Table A3)		

Table A2 (Continued)
NBS Plumbing Wall Test

NBS Test No.	Construction	Cavity No.	Stack	Lateral	Fire Performance
7	2 x 6" wood stud 5½" cavity 5/8" X-GWB on both faces All pipe penetrations in cavities 1 & 3 sealed with plaster spackling compound	1	3" ABS	1½" ABS	Satisfactory (slight excess temperature rise in last three minutes of test)
		3	3" PVC	1½" PVC	Satisfactory (slight excess temperature in last three minutes of test)
		2,4	(Penetrations not sealed – see Table A3)		
8	Double row of 2 x 4" wood studs 9½" cavity 5/8" X-GWB on both faces All pipe penetrations sealed with plaster spackling compound	1	4" ABS	1½" ABS	Failed by "flame through at 44 minutes after lower P trap fell off"
		2	4" PVC	1½" PVC	Satisfactory
		3	4" ABS	2" ABS	Satisfactory
		4	4" PVC	2" PVC	Satisfactory

Table A3
NBS Tight Clearance and Unsealed Experiments

NBS Test No.	Construction	Cavity No.	Stack	Lateral	Fire Performance
3	2 x 4" wood stud 3½" cavity 5/8" X-GWB on both faces All pipe penetrations sealed with plaster Hubs penetrated GWB	1	2" PVC	1½" PVC	Excess temp. at TC 12 at 51 min.
		2	2" Copper	1½" Copper	Excess temp. at lower lateral at approx. 32 min. – charring around upper lateral.
		3	2" ABS	1½" ABS	Flame through at lower lateral at 42 min., excess temp. at 43 min.
		4	2" Iron	1½" Iron	Satisfactory test stopped at 56 min.
5	Double row of 2 x 4" wood studs 1½" cavity 5/8" X-GWB on both faces All pipe penetrations sealed with plaster spackling compound 4" hubs penetrated GWB	1	4" PVC	4" x 1½-1½"	Excess temp. at lower lateral at 39 min.
		3	4" ABS	4" x 1½-1½"	Flame through at lower lateral.

Table A3 (Continued)
NBS Tight Clearance and Unsealed Experiments

NBS Test No.	Construction	Cavity No.	Stack	Lateral	Fire Performance
6	2 x 4" steel studs 3½" cavity 5/8" X-GWB on both sides	1	2" ABS	1½" ABS	Excess temp. and flame through at lower lateral at 28 min.
	All but Cavity 2 sealed with plaster spackling compound	2	2" ABS	1½" ABS	Excess temp. at lower lateral at 9 min. and flame through at 19 min.
		3	2" ABS	1½" ABS	Excess temp. at lower lateral at 17 min. and flame through at 25 min.
		4	2" PVC	1½" PVC	Excess temp. at lower lateral, TC10, TC11, and ignition of cotton pad at 56 min.
7	2 x 6" wood stud 5½" cavity 5/8" X-GWB on both faces	2	2" ABS	1½" ABS	Excess temp. at lower lateral at 19 min. and flame through in 28 min.
	All pipe penetrations in cavities 2 and 4 not sealed	4	2" PVC	1½" PVC	Flame through at lower lateral at 27 min.
9	2 x 6" wood stud 5½" cavity 5/8" X-GWB on both faces	1	2" Copper	1½" Copper	Excess temp. rise at *both* upper and lower laterals on unexposed face at approx. 28 min.
	Not sealed-all holes 1" oversize	2	2" PVC	1½" PVC	Excess temp. rise at lower lateral at 25 min.
		3	2" ABS	1½" ABS	Lateral offset from stack. Excess temp. rise at lower lateral at 23 min. and upper at 40 min.
		4	2" ABS	1½" ABS	Lateral offset from stack different stud space. Excess temp. rise at lower lateral at 10 min. and cotton pad ignited at 21 min.
10	2 x 4" steel stud 3½" cavity Glass fiber insulation 5/8" X-GWB on both faces	1	2" ABS	1½" ABS	Excess temp. rise at lower lateral at approx. 23 min. and at TC 10 at 45 min., flame through at 25 min.
		2	2" PVC	1½" PVC	Flame through at upper lateral
	Cavities 1 and 2 sealed with plaster spackling compound All holes 1" oversize	3	2" ABS	1½" ABS	Excess temp. rise at lower lateral at 15 min., at TC 11 at 46 min., and TC 10 at 50 min. Flame through at upper lateral at 22 min.
		4	2" PVC	1½" PVC	Excess temp. rise at lower lateral at 23 min. and TC 10 at 45 min. Flame through at 35 min.

Table A4
UCB Plumbing Wall Tests

UCB Test No.	Construction	Cavity No.	Stacks and Laterals	Fire Performance
1 (2A) 29 July 1975	2" x 6" wood stud 5½" cavity 5/8" X-GWB on both faces (applied horizontally)	1	ABS	Satisfactory
	All pipe penetrations sealed (from outside) with a vermiculite-plaster mixture	2	PP	Failed by high temperature at 55 min. and flame-through at lower lateral at 57 min.
	Metal lavatories mounted on both sides of exposed wall specimen.	3	PVC	Failed by high temperature at 53 min.
2 (2B) 15 August 1975	2" x 6" wood stud 5½" cavity 5/8" X-GWB on both faces (applied vertically)	1	ABS	Failed by high temperature at 47 min. and flame-through at lower lateral at 49 min.
	All pipe penetrations sealed (from outside) with a vermiculite-plaster mixture	2 (no back-face lateral)	PP	Failed by high temperature at 56 min.
	Lavatories simulated with brackets.	3	PVC	Satisfactory
3 (2C) 23 August 1975	2" x 6" wood stud 5½" cavity	1	ABS	Satisfactory
	5/8" X-GWB (vertical)	8	PP	Satisfactory
	9 separate plumbing cavities with a variety of protection methods (fall-off of GWB on cavities 2-7 prevented completion of test on those cavities). Mineral wool batt protection methods.	9	PVC	Satisfactory
4 (2D) 3 September 1975	2" x 6" wood stud 5½" cavity 5/8" X-GWB on both faces (vertical)	1	ABS	Failed by flame-through at lower lateral at 33 min. Satisfactory in all other ways.
	4-ft batts of mineral wool on both sides of pipe from	2	PP	Satisfactory
	floor, and mineral wool backpacked around pipe where lateral penetrates GWB	3	PVC	Satisfactory
5 (2E) 20 February 1976	2" x 6" wood stud 5½" cavity 5/8" X-GWB on both faces	1	ABS	Failed by flame-through at lower lateral at 39 min.
	(vertical) 16" x 16" x 3" thick inorganic fiberbatts placed behind each penetration and joint compound in space around laterals	2 3	PVC) ABS)	Both failed by flame-through at lower lateral at 58 min. All cavities satisfactory in other ways.

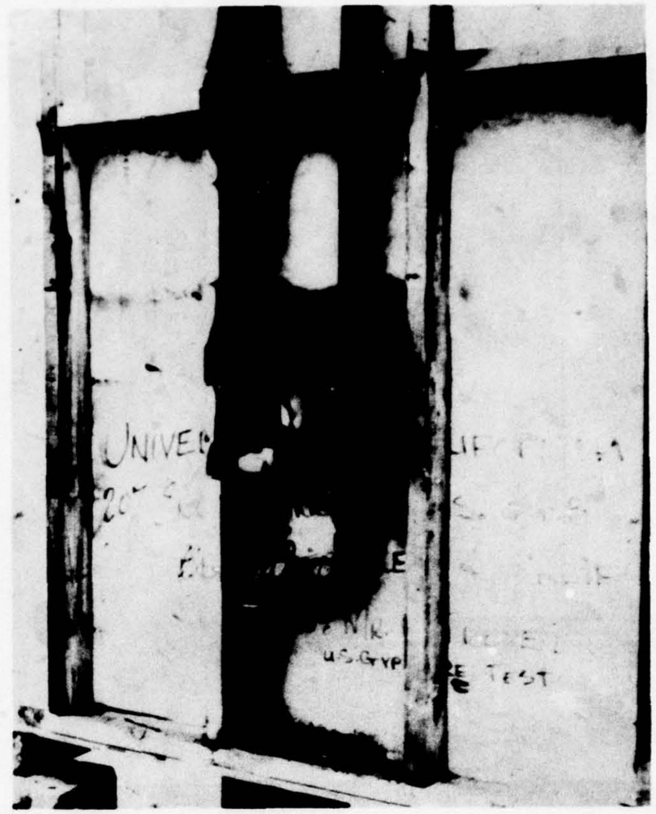
Table A4 (Continued)
UCB Plumbing Wall Tests

UCB Test No.	Construction	Cavity No.	Stacks and Laterals	Fire Performance
6 (2F) 19 July 1976	2" x 6" wood stud 5½" cavity 5/8" X-GWB on both faces (vertical)	1	ABS	Failure with flame out the drain at 50 min. Satisfactory in all other ways.
	Cavity 1-24" x 14½" x 1" thick fiberglass duct liner fixed with wire to both sides of pipe above lateral penetration.	2	ABS	Satisfactory
	Cavity 2-16" x 14½" x 1" thick mineral wool batts centered at lateral-both sides. Cavity 3-24" x 14½" x 1" mineral wool wired to pipe as in cavity 1.	3	ABS	Satisfactory
7 (2G) 26 August 1976	2" x 6" wood stud 5½" cavity	1	PVC	Satisfactory
	5/8" X-GWB on both faces (vertical)	2	ABS	Satisfactory
	18" x 24" 24-gauge galvanized steel sheet surrounding each pipe. see Figures A4 and A5	3	ABS	Satisfactory
8 (2H) 3 September 1976	2" x 6" wood stud 5½" cavity	1	PVC	Satisfactory
	5/8" X-GWB on both faces (vertical)	2	PVC	Satisfactory
	18" x 24" 24-gauge galvanized steel sheet surrounding each pipe, see Figures A4 and A5	3	ABS	Satisfactory

(a) (b)

Figure A1. (a) Two-story mock-up in foreground has ABS DWV pipe in wall as drawn on surface of gypsum wallboard.
(b) Flames engulf the wooden cabinet and reach ceiling at 11 minutes into experiment.

(c)



(d)

Figure A1. (c) Fire was extinguished at 22 minutes and this shows the remains of the kitchen cabinet.
(d) After the exterior redwood siding was removed, part of the sink tee was burned and the vent pipe had folded over at the tee to close itself.

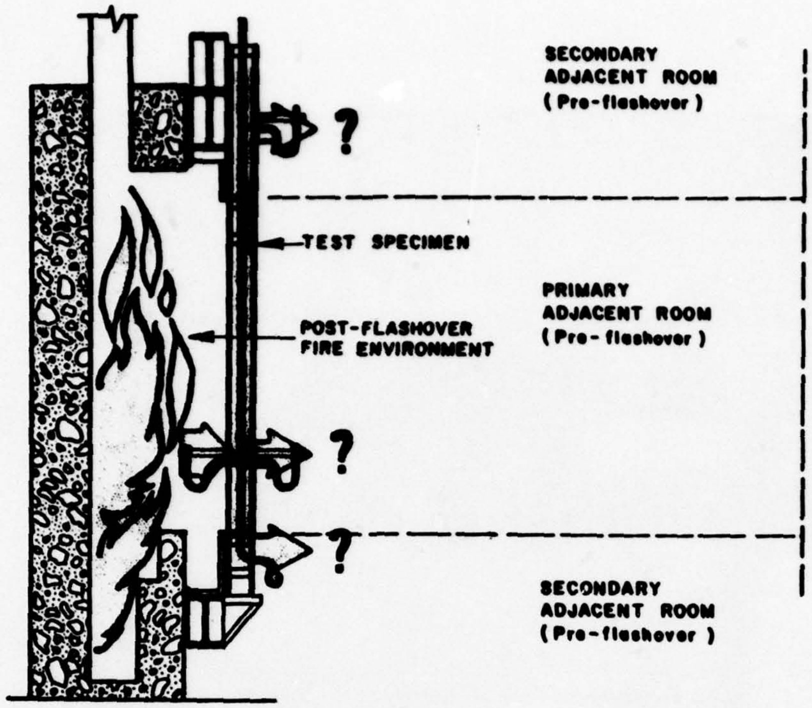


Figure A2. A schematic diagram of how DWV systems have been exposed to E119 fire tests of walls.

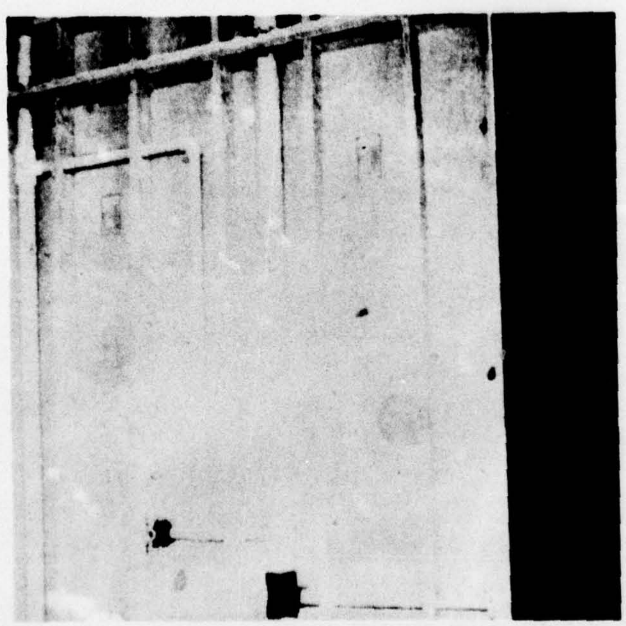


Figure A3. Shows typical DWV system in OSU tests before the gypsum wallboard had been installed on the exposed face. The black patches visible around penetrations were made with a commonly available furnace setting cement.

Construction Details for the UCB wall shown in Figure A4:

General Notes:

Wall constructed with 5/8" type "X" gypsum wallboard nailed with 6d cooler nails at 7" on center with end joints on nailing members. All drywall joints filled and taped. Conforms to one hour rated construction per the Uniform Building Code.

(1) Wall area shielded from furnace
(2) Wall area open to furnace
(3) 4" ABS header. After wall is in place at furnace, make no hub connection to 4" ABS line from direct sewer connection.
(4) Terminate vent stack to atmosphere
(5) 2 x 4 horizontal plates (typ)
(6) 5/8 plywood subfloor (typ)
(7) 2 x 4 wood studs @ 16" O.C. (typ)
(8) Riser clamp locations
(9) 24 ga sheet metal 18" H x 24" W

Piping Notes:

$\boxed{2}$ 2 x 1½ double figure # 4 fitting

$\boxed{4}$ 2 x 1½ single figure # 4 fitting

Δ Indicate thermocouple locations

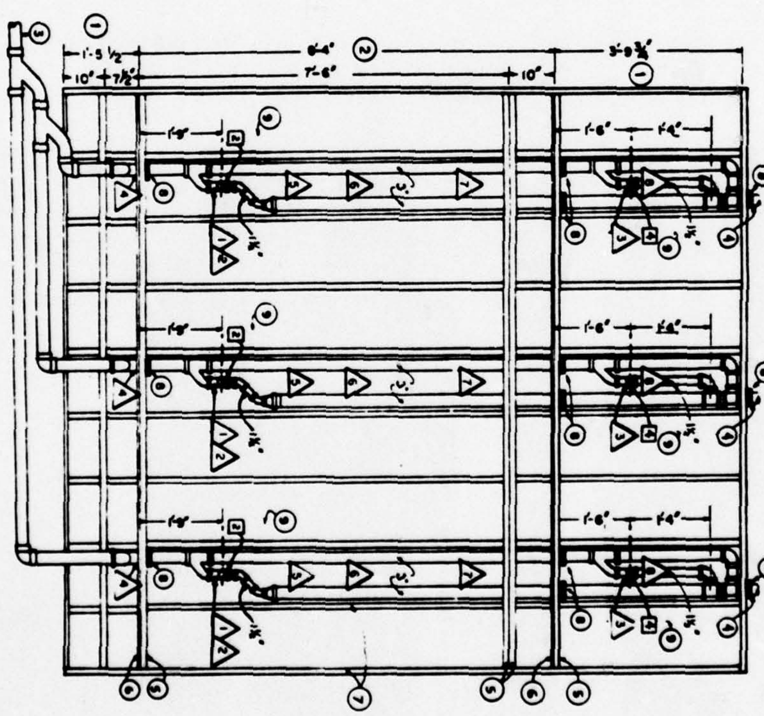


Figure A4. Drawing showing the construction of a UCB test specimen with three plumbing cavities. The rectangular shaded areas around each lateral represent the 24-gauge galvanized steel sheets which protect the back-to-back lateral penetrations.

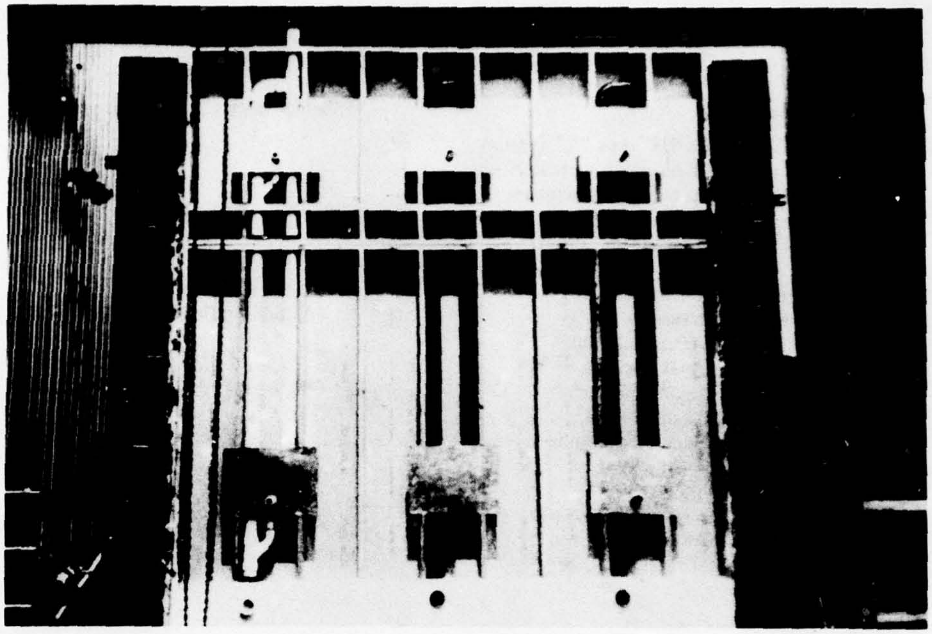


Figure A5. (a) UCB wall assembly prior to test. Note the two floors and the simple sheet metal sheets at each penetration.

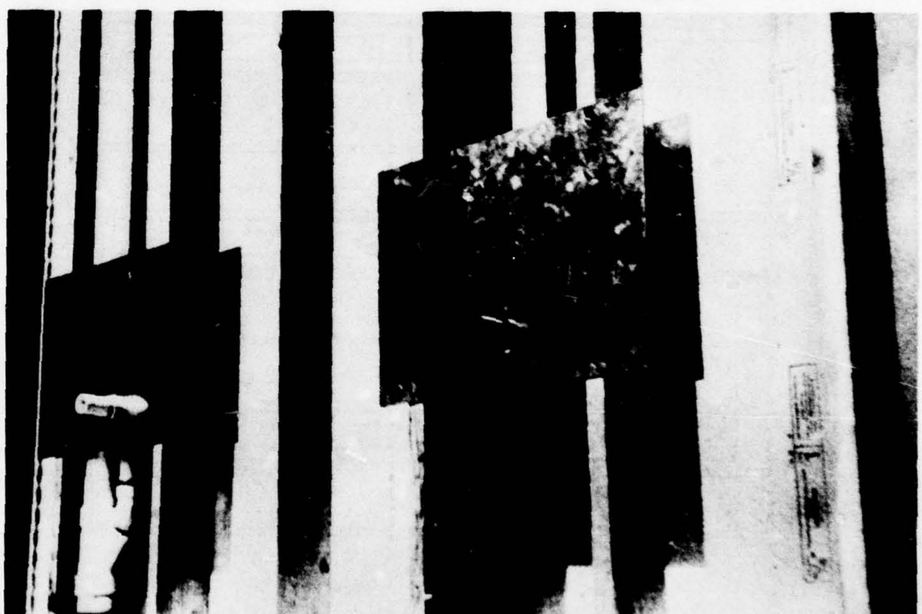


Figure A5. (b) A close-up photograph of two cavities showing the metal sheets at a slightly oblique angle.

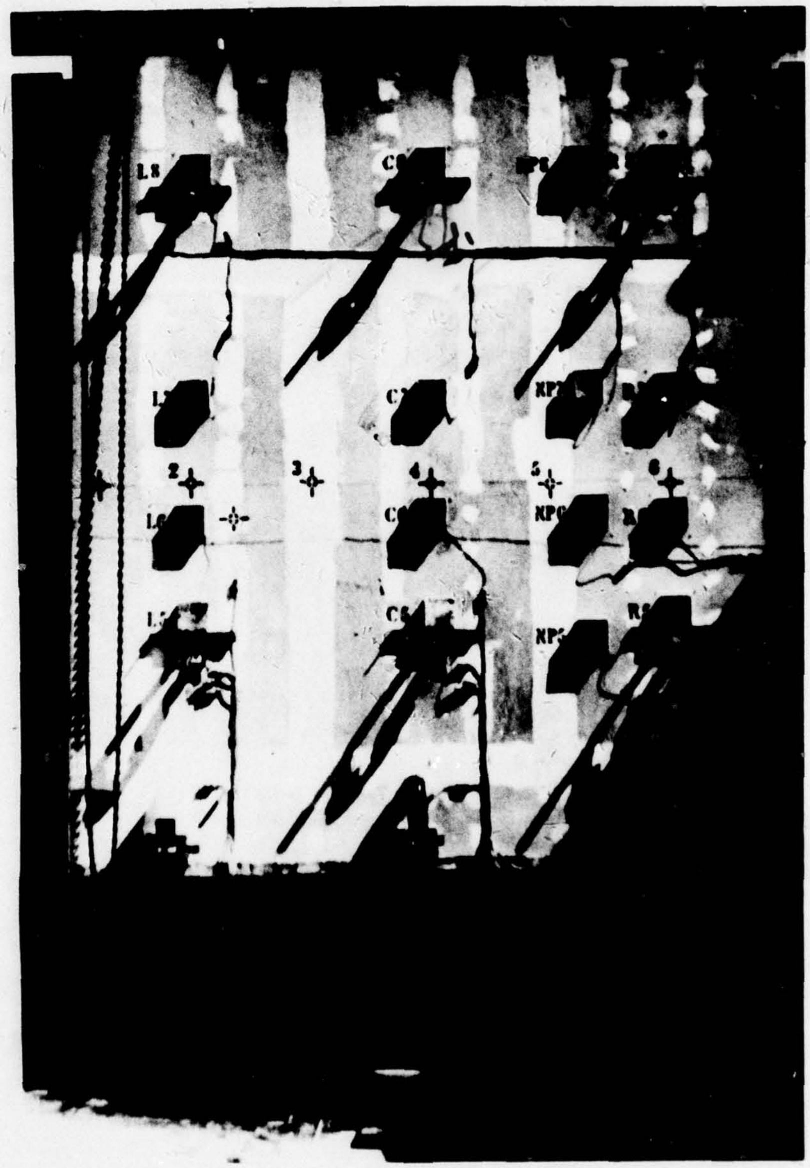


Figure A6. The unexposed face of the wall specimen shown in Figure A5 after the 1-hour fire exposure. There was no flame-through or hot spots observed during the test.

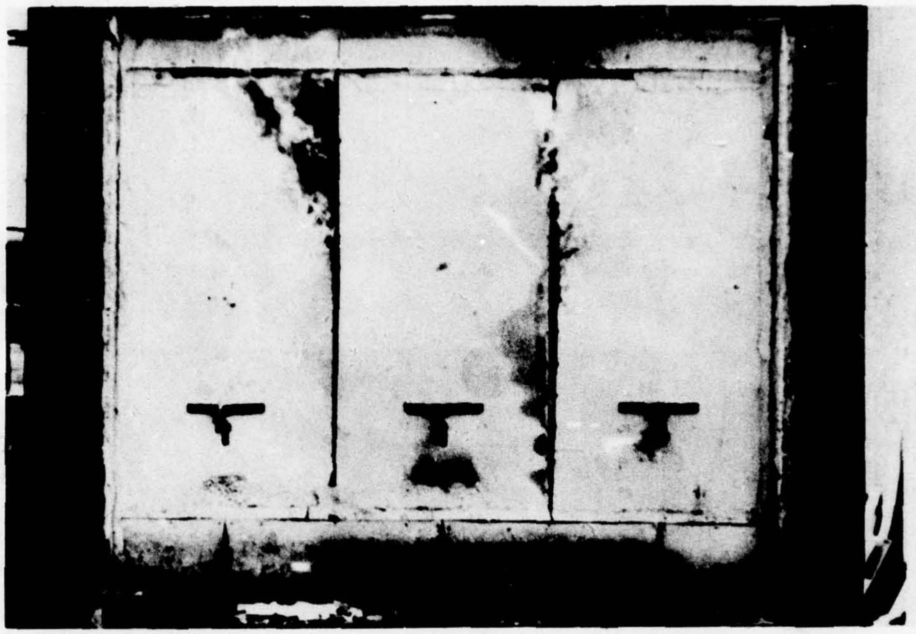


Figure A7. (a) Exposed face of the wall specimen shown in Figures A5 and A6 after the 1-hour fire exposure. Note that the gypsum wallboard is still in place.

Figure A7. (b) A view of the same specimen after some of the exposed wallboard has been removed. A plug of molten plastic has formed at the bottom of each plumbing cavity to block the fire from going to the floor below.

Figure A7. (c) A close-up of two cavities showing the plug formed by the collapsed pipe.

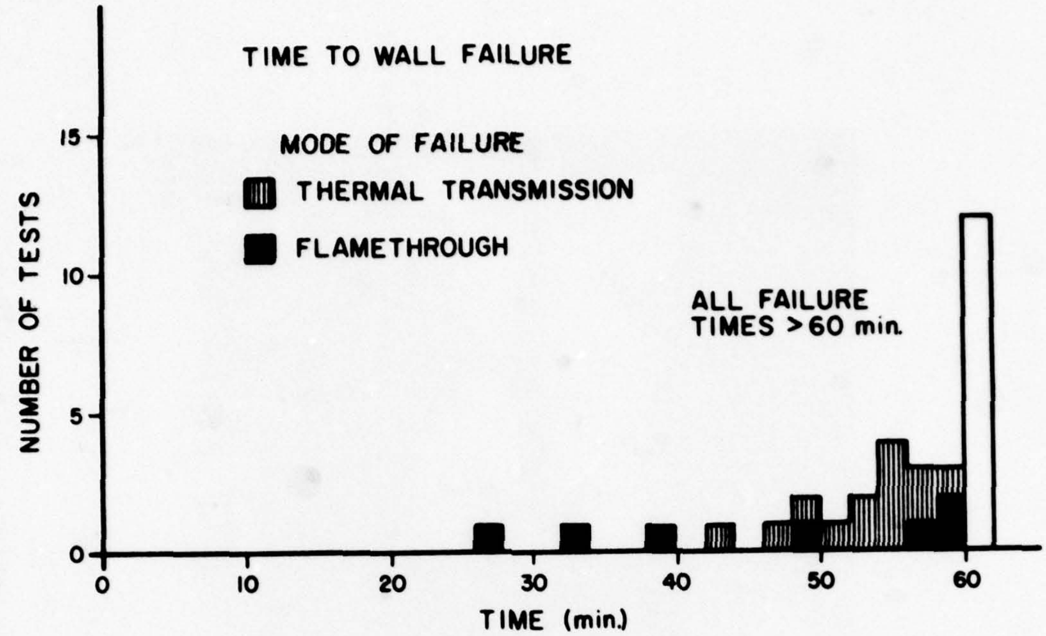


Figure A8. (a) Histogram of "time-to-failure" of UCB and NBS wall cavities containing plastic DWV plumbing systems.

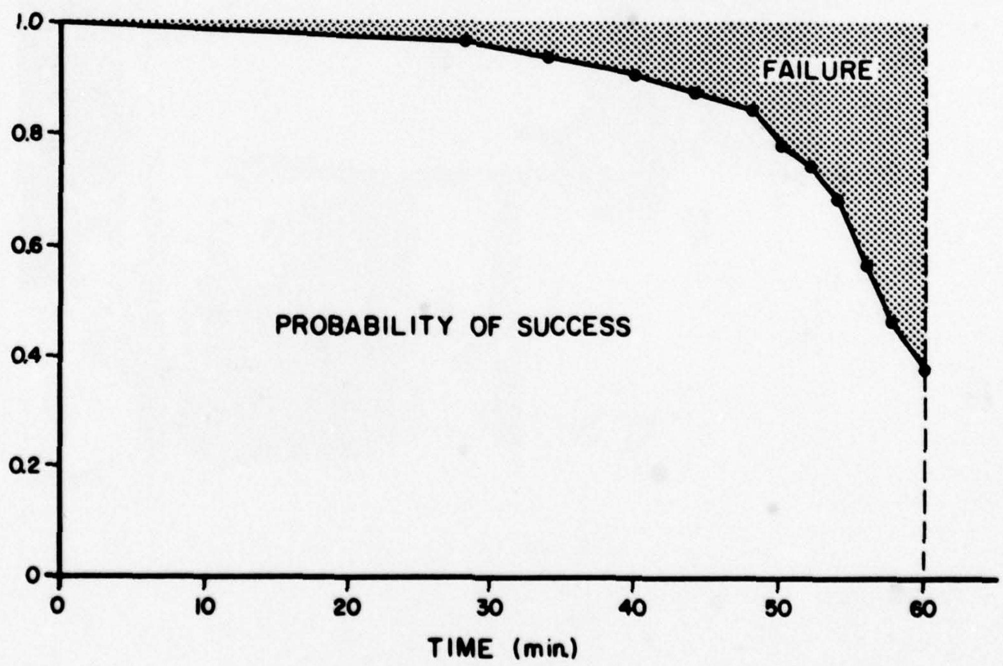


Figure A8. (b) Given the NBS and UCB data, the probability of success is shown (see text for discussion).

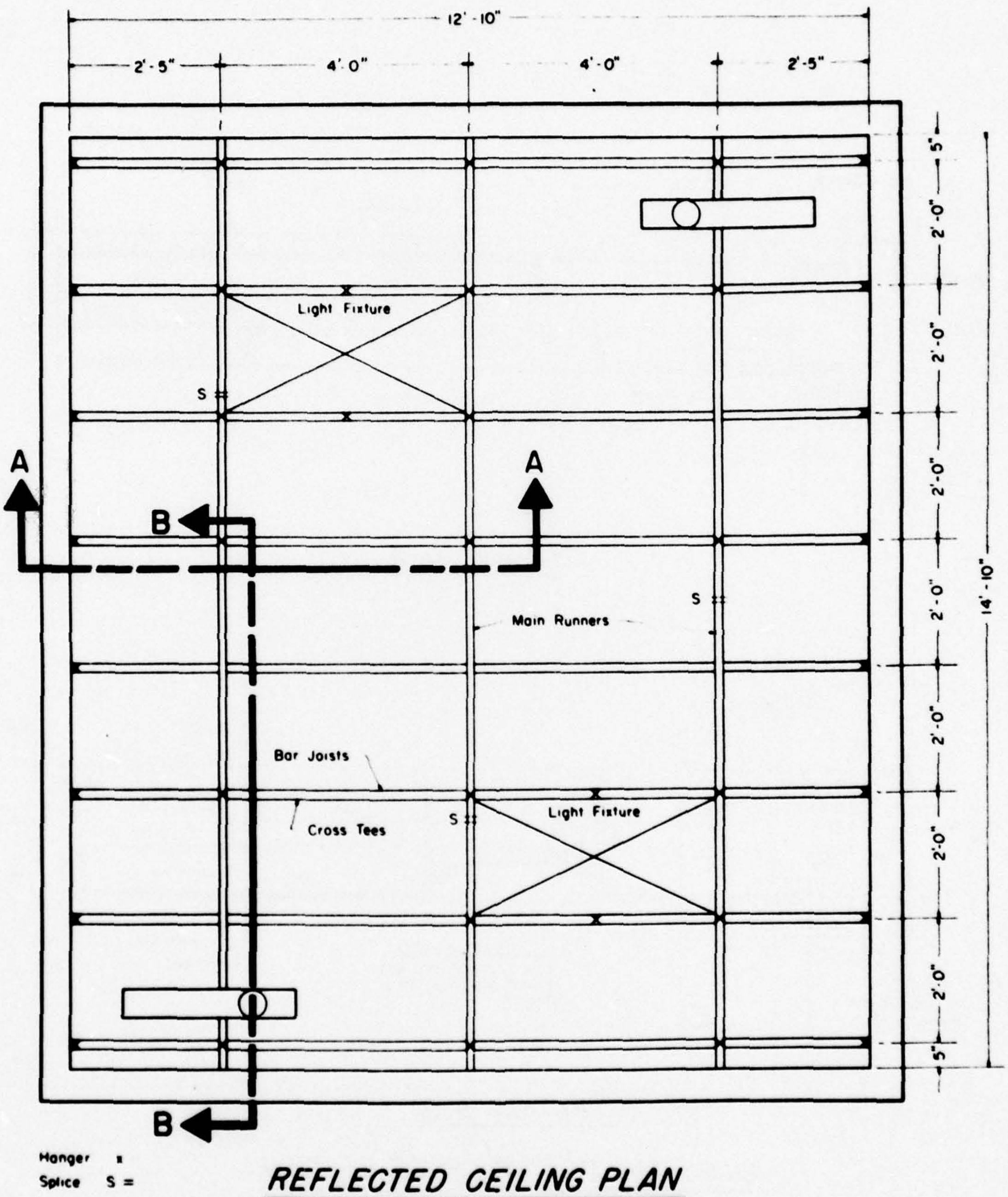
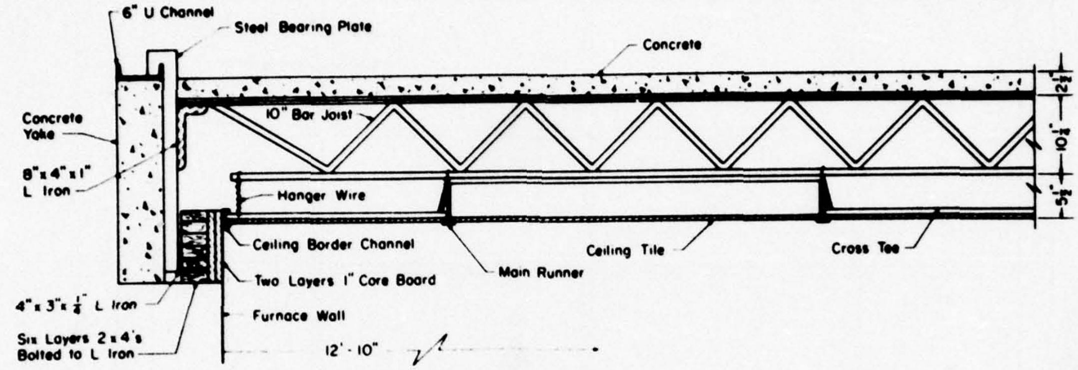
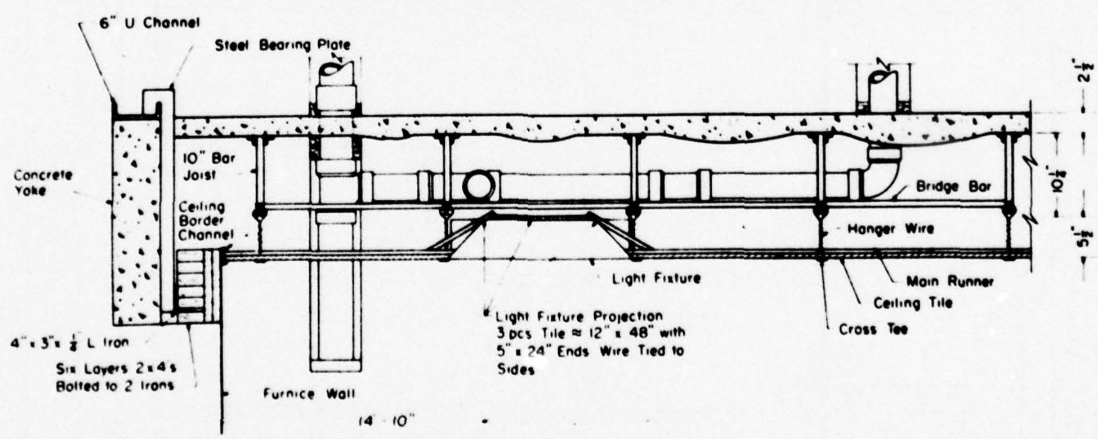


Figure A9. (a) Plan view of OSU floor and ceiling assembly showing location of the cross sections A-A and B-B as well as details and dimensions.



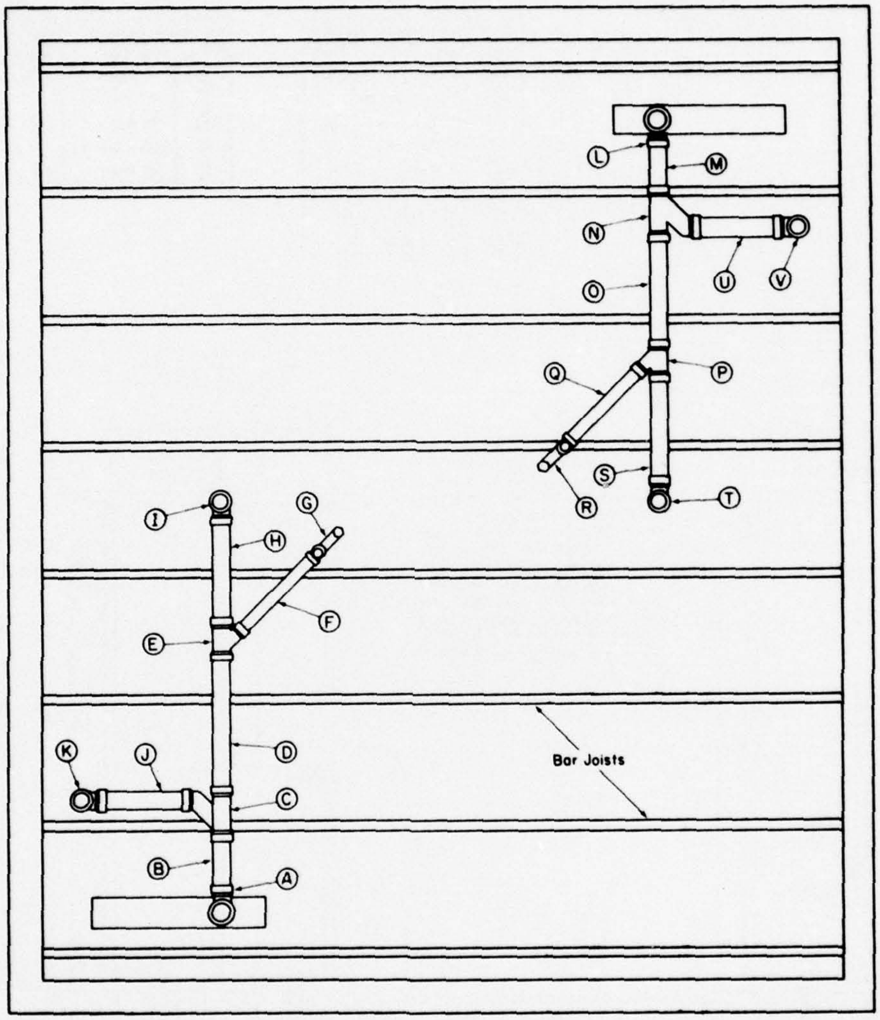
SECTION A-A



SECTION B-B

FLOOR AND CEILING CROSS SECTION

Figure A9. (b) Cross sections A-A and B-B. Note the location of the pipe in section B-B and the stub walls above and below the assembly.



Part Let	Description	Length
A	4" x 4" x 3" ABS San Tee	
B	3" ABS Pipe	9"
C	3" ABS WYE and $\frac{1}{8}$" Bend	
D	3" ABS Pipe	$22\frac{1}{4}$"
E	3" x 3" x 2" ABS WYE	
F	2" ABS Pipe	$18\frac{1}{4}$"
G	2" P Trap and $1\frac{1}{2}$" S Joint Adpt	

Part Let	Description	Length
H	3" ABS Pipe	$20\frac{3}{8}$"
I	3" ABS $\frac{1}{4}$ Bend	
J	3" ABS Pipe	$17\frac{1}{4}$"
K	3" ABS $\frac{1}{4}$ Bend	
L	4" x 4" x 3" PVC San Tee	
M	3" PVC Pipe	10"
N	3" PVC WYE and $\frac{1}{8}$" Bend	

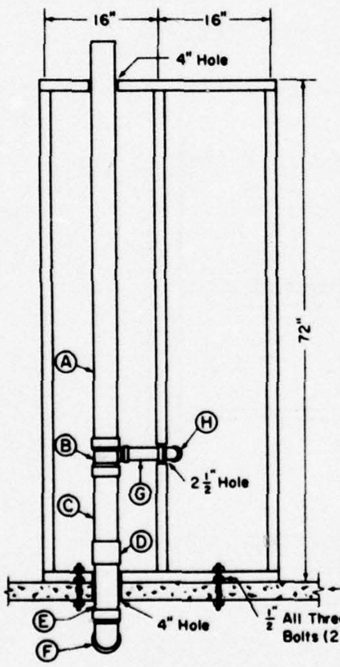
Part Let	Description	Length
O	3" PVC Pipe	26"
P	3" x 3" x 2" PVC WYE	
Q	2" PVC Pipe	$21\frac{3}{8}$"
R	2" P Trap and $1\frac{1}{2}$" S Joint Adpt	
S	3" PVC Pipe	$21\frac{1}{8}$"
T	3" PVC $\frac{1}{4}$ Bend	
U	3" PVC Pipe	$17\frac{1}{2}$"
V	3" PVC $\frac{1}{4}$ Bend	

REFLECTED PLUMBING VIEW

Figure A10. **(a)** Reflected plumbing view of the OSU assembly.

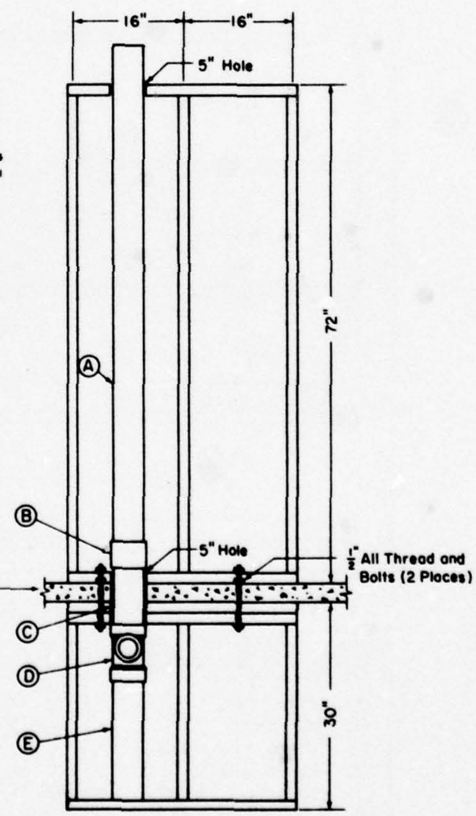
Plumbing Parts for Detail 2		
Part Let	Description	Length
A	3" Pipe	58"
B	$3 \times 3 \times 1\frac{1}{2}$ San-Tee	
C	3" Pipe	$12\frac{1}{4}$"
D	3" Coupling	
E	3" Pipe	$9\frac{1}{2}$"
F	3" - $\frac{1}{4}$ Bend	
G	$1\frac{1}{2}$" - Pipe	6"
H	$1\frac{1}{2}$" - $\frac{1}{4}$ Bend	

Plumbing Parts for Detail 1		
Part Let	Description	Length
A	4" Pipe	$72\frac{3}{8}$"
B	4" Coupling	
C	4" Pipe	$11\frac{1}{2}$"
D	$4 \times 4 \times 3$ San-Tee	
E	4" Pipe	$18\frac{3}{8}$"



CONSTRUCTION

Framing - Nominal 2 x 6 Southern Pine Fastened with 16d Smooth Box Nails
Wallboard - Nominal 5/8" Type X Gypsum Board Two Layers with Inner Layer Attached with 6d Cement Coated Nails 6" OC Outer Layer Attached Over Inner Layer with 8d Cement Coated Nails 8" OC All Vertical Joints on Studs All Surfaces to be Covered with Wallboard Except Top Edge of Lower Wall and Bottom Edge of Upper Wall All Joints Covered with Tape and Joint Compound



WALL DETAILS

Figure A11. Details of the vertical plumbing and the stud walls which encased it.

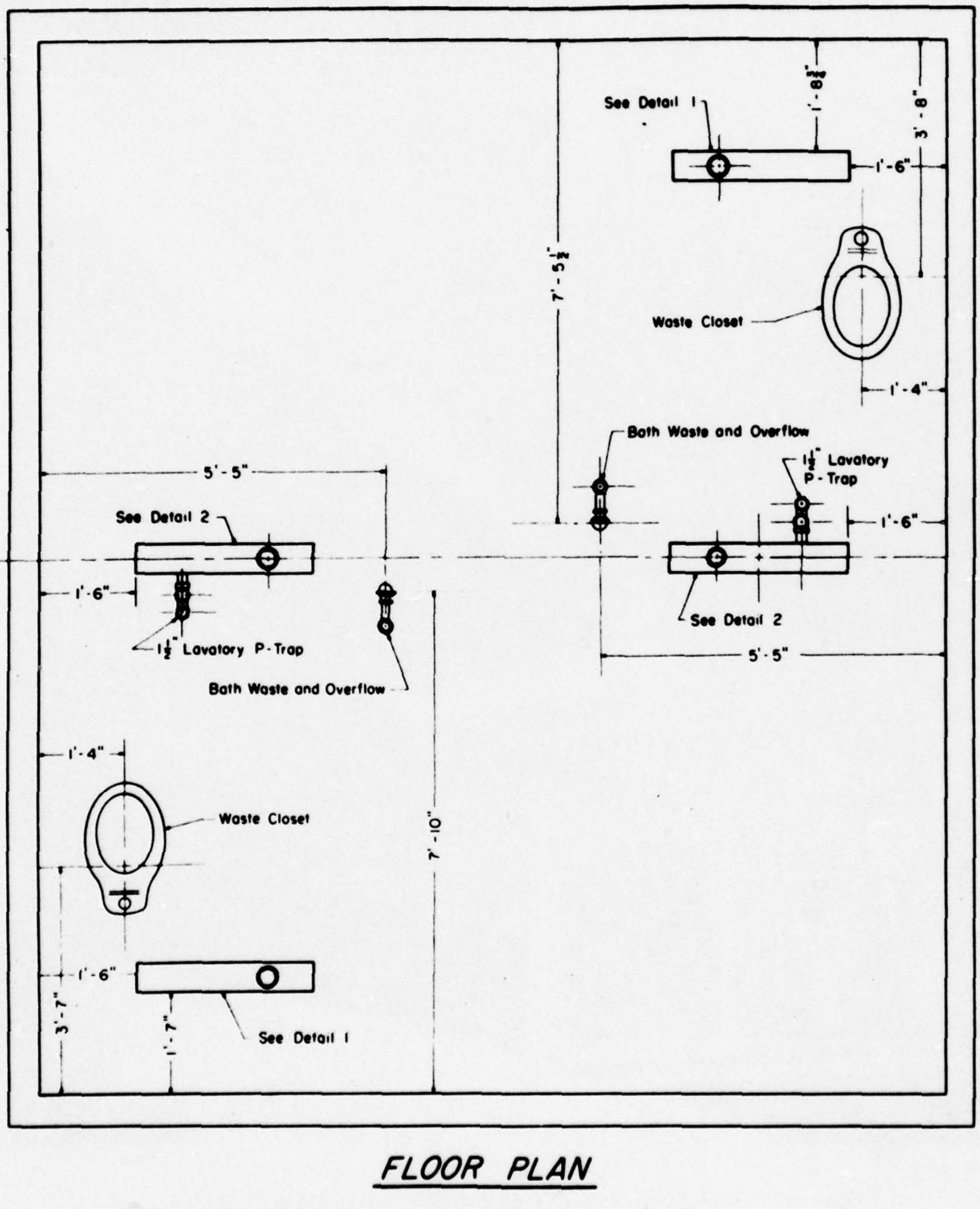


Figure A12. Layout of plumbing on floor of assembly.

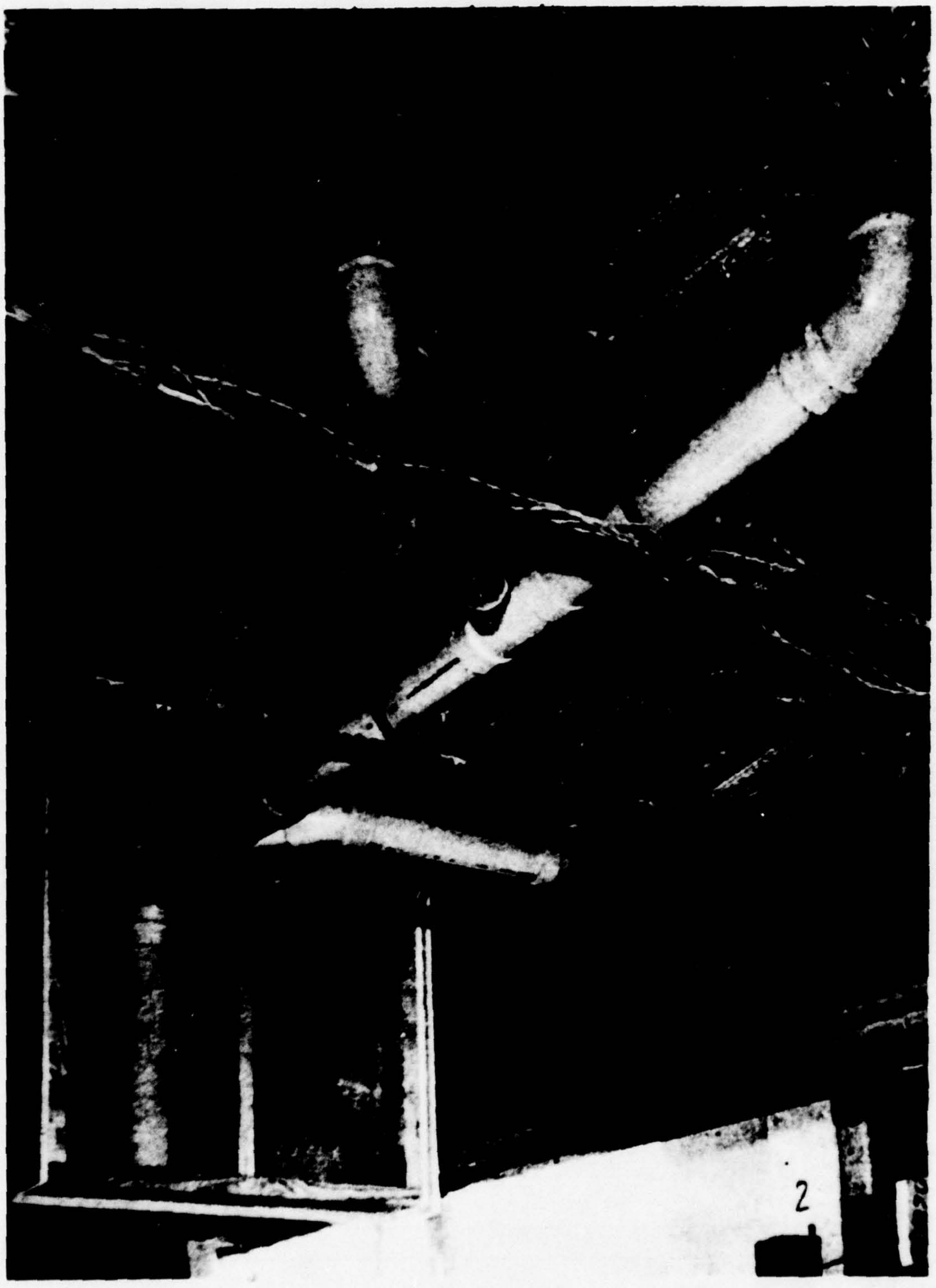
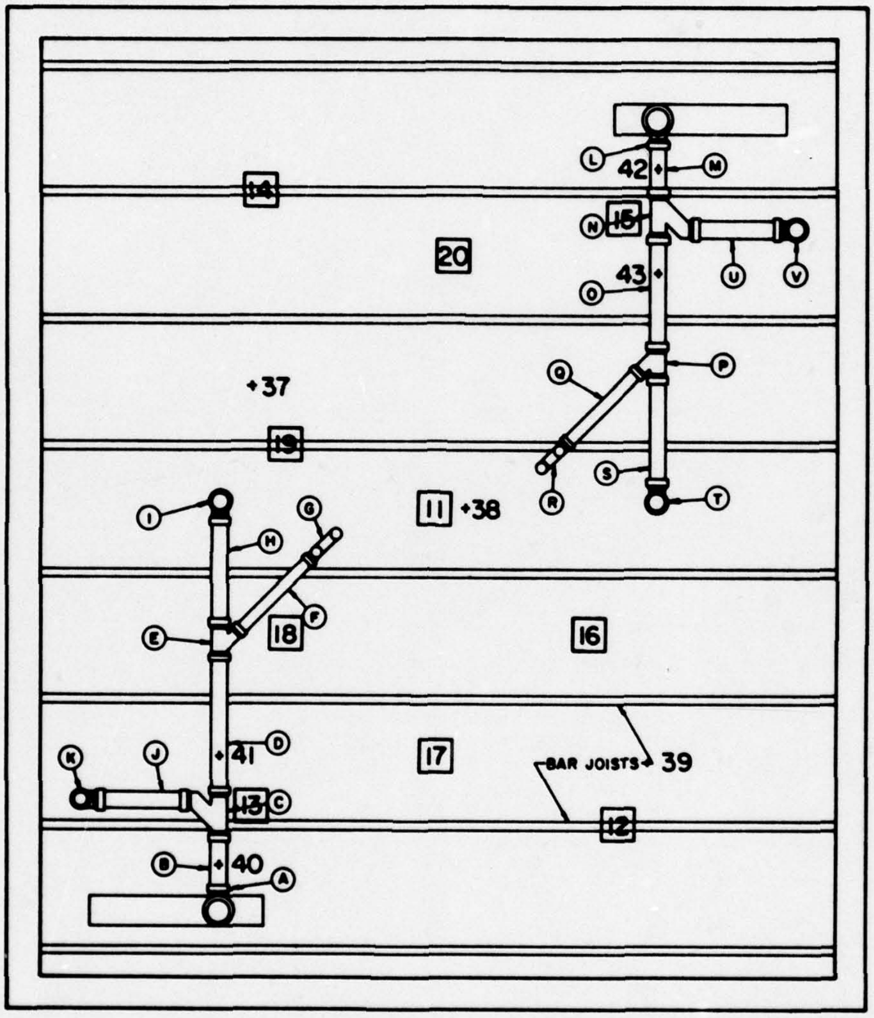


Figure A13. Photograph of the PVC plumbing run and stub wall before test. Note that the wallboard on one side of the stub wall was not yet in place.



INTERIOR THERMOCOUPLES

37,38,39 - Plenum
40,41 - on PVC Pipe
42,43 - on ABS Pipe

Figure A14. Locations of unexposed surface and interior thermocouples on OSU assembly.

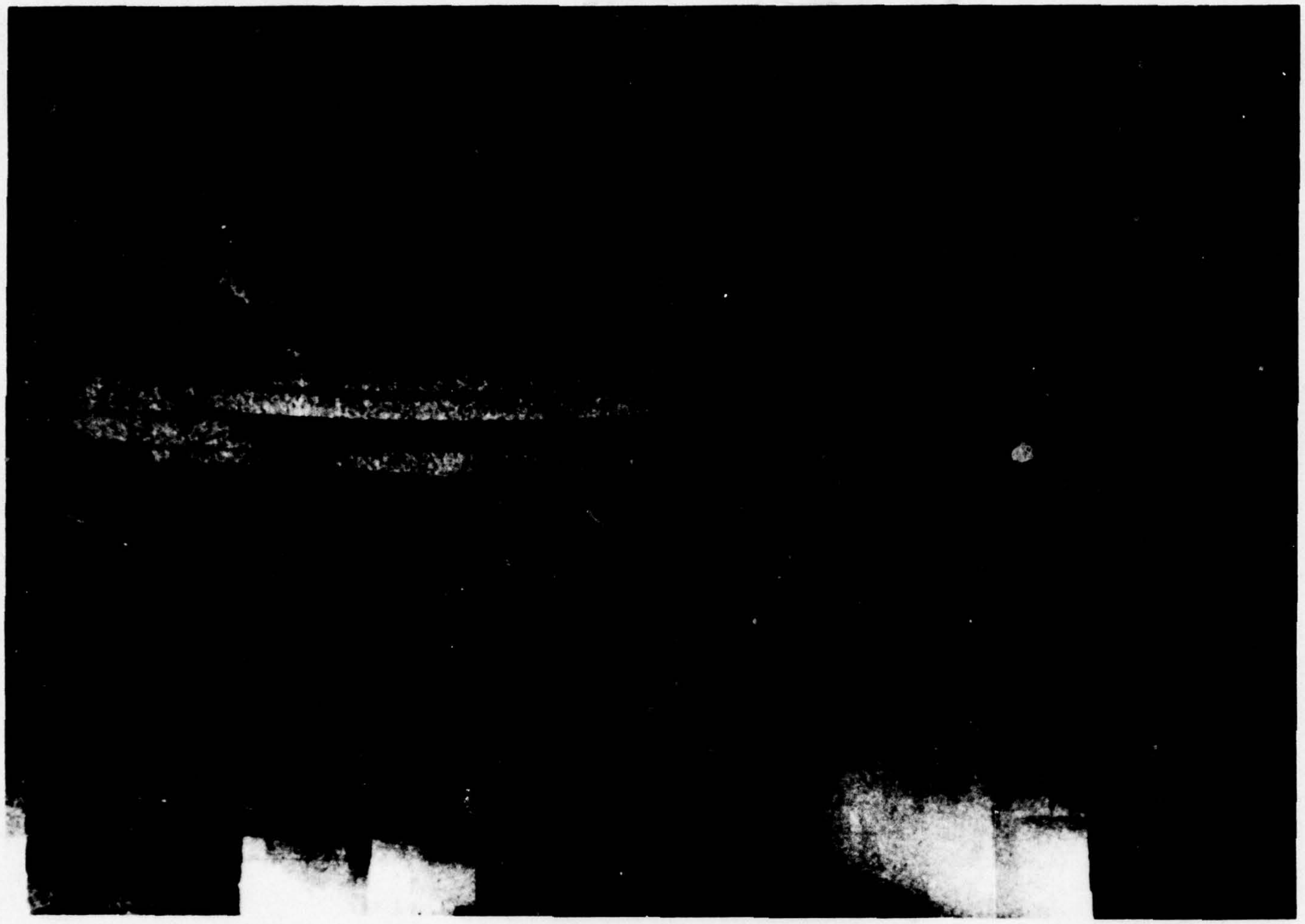


Figure A15. Exposed surface at 60 minutes. Note the discoloration of the ceiling tile due to pipe material.

TIME MINUTES	AVG FURN TEMP	STD FURN TEMP	11	12	13	14	15	16	17	18	19	20	AVG SURF TEMP
			UNEXPOSED SURFACE TEMPERATURES										
0.0	70	68	70	70	70	70	70	70	70	70	70	70	70
5.0	1024	1000	75	75	75	75	75	75	75	75	75	75	75
10.0	1294	1300	75	75	75	75	75	75	75	75	75	75	75
15.0	1385	1399	75	75	75	75	75	75	75	75	75	75	75
20.0	1499	1462	75	80	80	80	80	75	75	75	80	75	77
25.0	1498	1510	85	100	90	90	90	80	75	75	100	80	86
30.0	1501	1550	90	105	95	100	100	85	80	80	110	85	93
35.0	1579	1584	105	120	105	110	110	95	90	85	125	100	104
40.0	1620	1613	110	130	115	120	120	100	95	95	145	105	113
45.0	1650	1638	125	150	130	135	130	110	105	100	175	120	128
50.0	1661	1661	140	165	145	150	145	125	115	110	190	130	141
55.0	1682	1681	150	180	155	165	155	135	125	120	200	150	153
60.0	1699	1700	165	200	175	180	175	150	135	130	205	175	169
65.0	1717	1718	180	220	195	200	200	165	150	150	220	195	187
70.0	1742	1735	195	230	200	220	200	175	165	160	230	200	197
75.0	1751	1750	210	240	210	230	210	195	180	175	245	210	210
80.0	1762	1765	225	250	220	245	220	210	200	195	260	215	224
85.0	1777	1779	230	260	230	250	230	225	215	205	275	225	234
90.0	1790	1792	245	275	245	255	245	230	225	225	295	225	246
95.0	1799	1804	250	295	255	265	250	240	235	230	310	230	256
100.0	1809	1815	255	315	270	275	265	250	245	240	340	240	269
105.0	1822	1826	260	330	285	295	275	250	250	245	360	245	279
110.0	1839	1835	270	350	300	315	290	245	250	240	390	245	289

NOTES
1. TEMPERATURES IN DEGREES FAHRENHEIT.

Figure A16. Time temperature data during fire endurance test of the floor and ceiling assembly at OSU.

TIME MINUTES	AVG FURN TEMP	STD FURN TEMP	37	38	39	40	41	42	43
			SUPPLEMENTARY TEMPERATURES						
0.0	70	68	70	70	70	70	70	70	70
5.0	1024	1000	225	320	240	230	230	240	230
10.0	1294	1300	365	415	370	315	325	335	325
15.0	1385	1399	450	475	450	400	375	405	405
20.0	1499	1462	500	520	505	450	435	460	475
25.0	1498	1510	565	595	575	500	500	465	505
30.0	1501	1550	580	620	600	520	495	510	550
35.0	1579	1584	585	610	635	535	495	545	550
40.0	1620	1613	660	665	690	575	530	610	620
45.0	1650	1638	710	700	730	610	575	660	660
50.0	1661	1661	745	720	765	675	610	675	685
55.0	1682	1681	770	750	800	640	650	690	700
60.0	1699	1700	800	790	850	660	700	720	725
65.0	1717	1718	835	815	860	680	755	745	745
70.0	1742	1735	855	845	895	700	880	780	760
75.0	1751	1750	845	880	920	765	840	800	780
80.0	1762	1765	855	925	960	825	860	820	810
85.0	1777	1779	905	965	995	825	900	840	845
90.0	1790	1792	960	1020	1020	910	940	855	885
95.0	1799	1804	1100	1310	1000	1040	1060	920	905
100.0	1809	1815	1150	1540	1165	1075	1110	1020	1005
105.0	1822	1826	1245	1505	1265	1110	1170	1125	1235
110.0	1839	1835	1225	1820	1370	920	1600	1180	1450

NOTES
1. TEMPERATURES IN DEGREES FAHRENHEIT.

Figure A17. Supplementary temperature data from the OSU test.

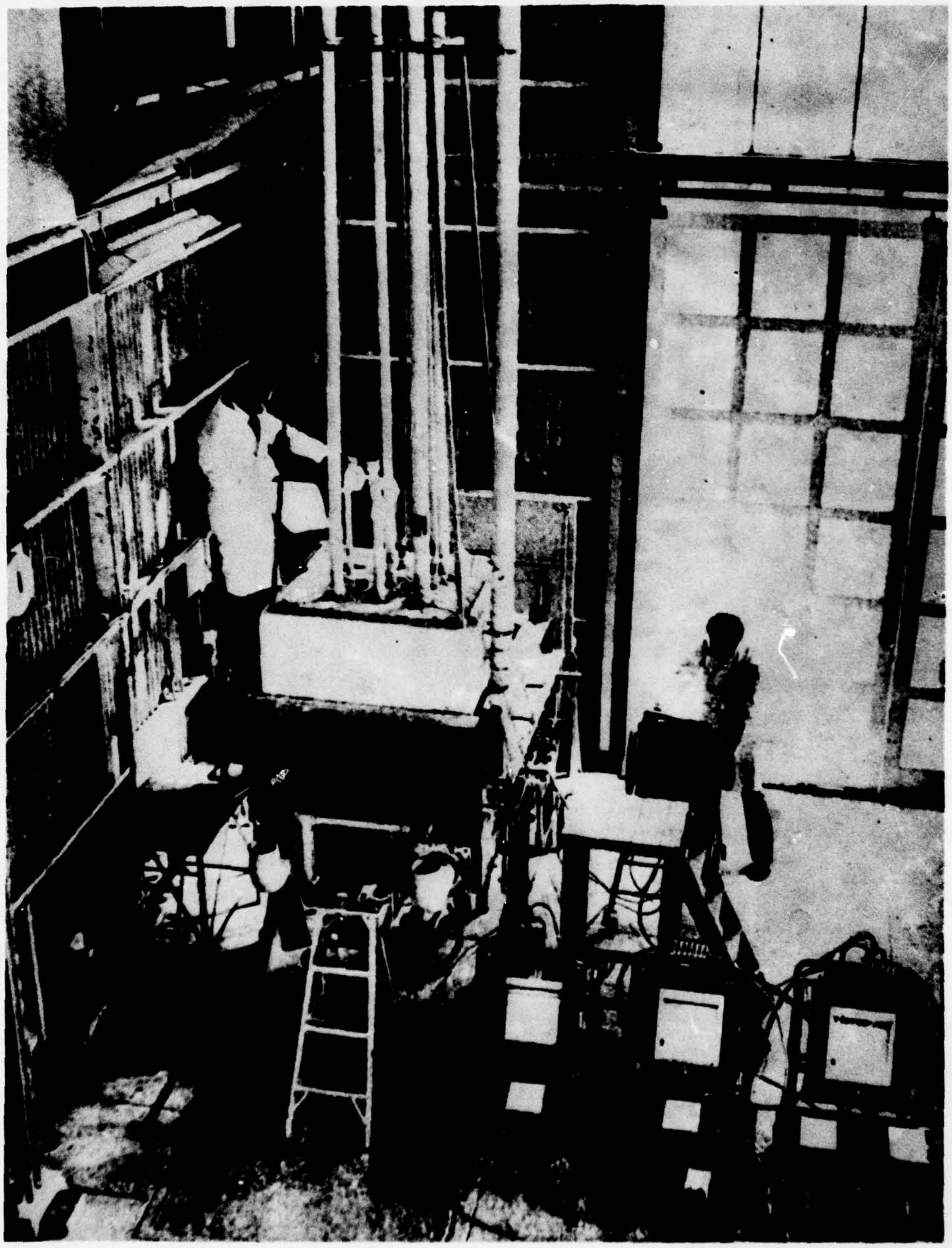


Figure A18. General view of the Australian testing facilities before the test on May 26, 1975.

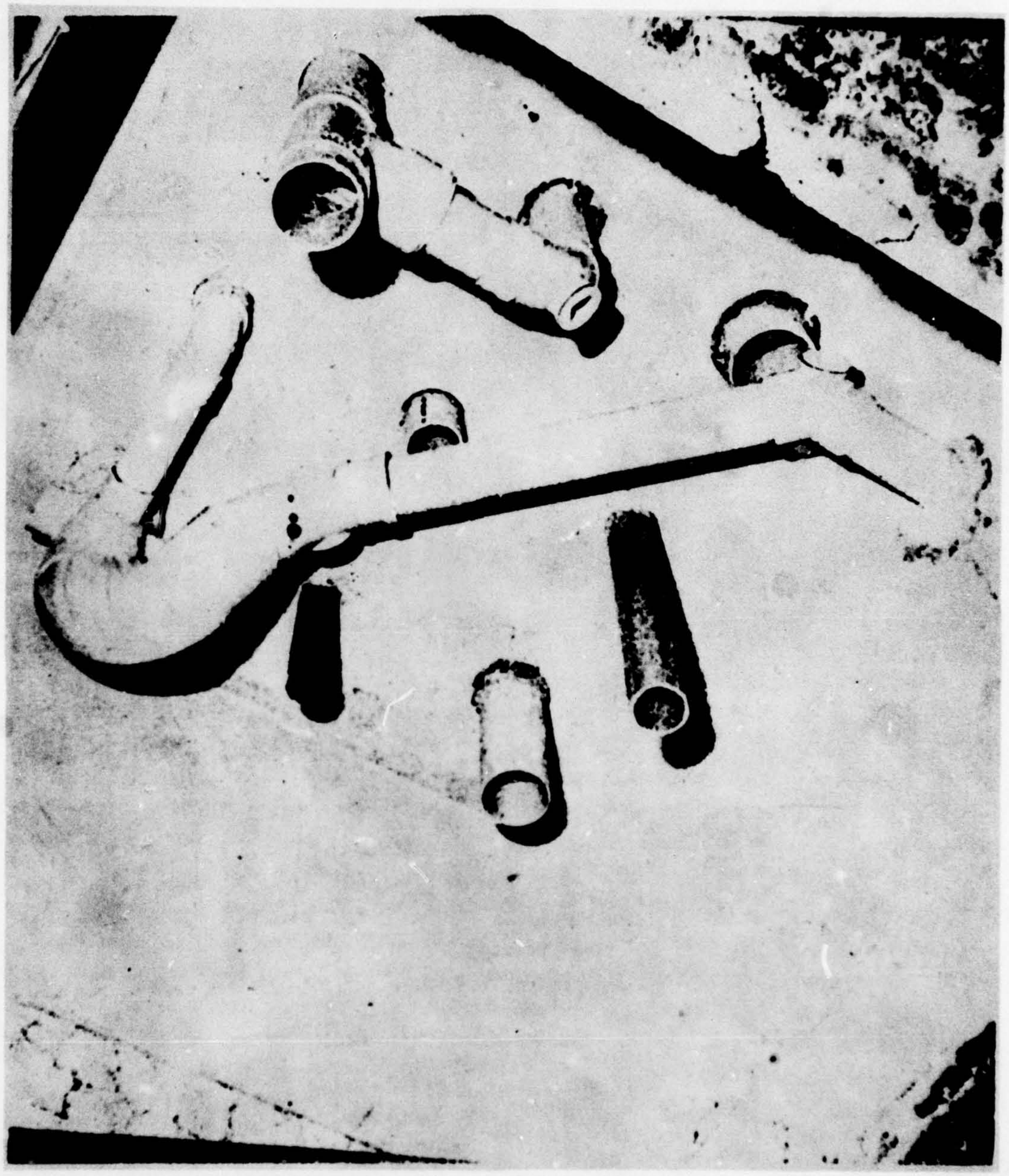


Figure A19. Photograph of the pipe and fitting below the floor slab in the Australian test on May 26, 1975. This is taken inside the furnace before the test.

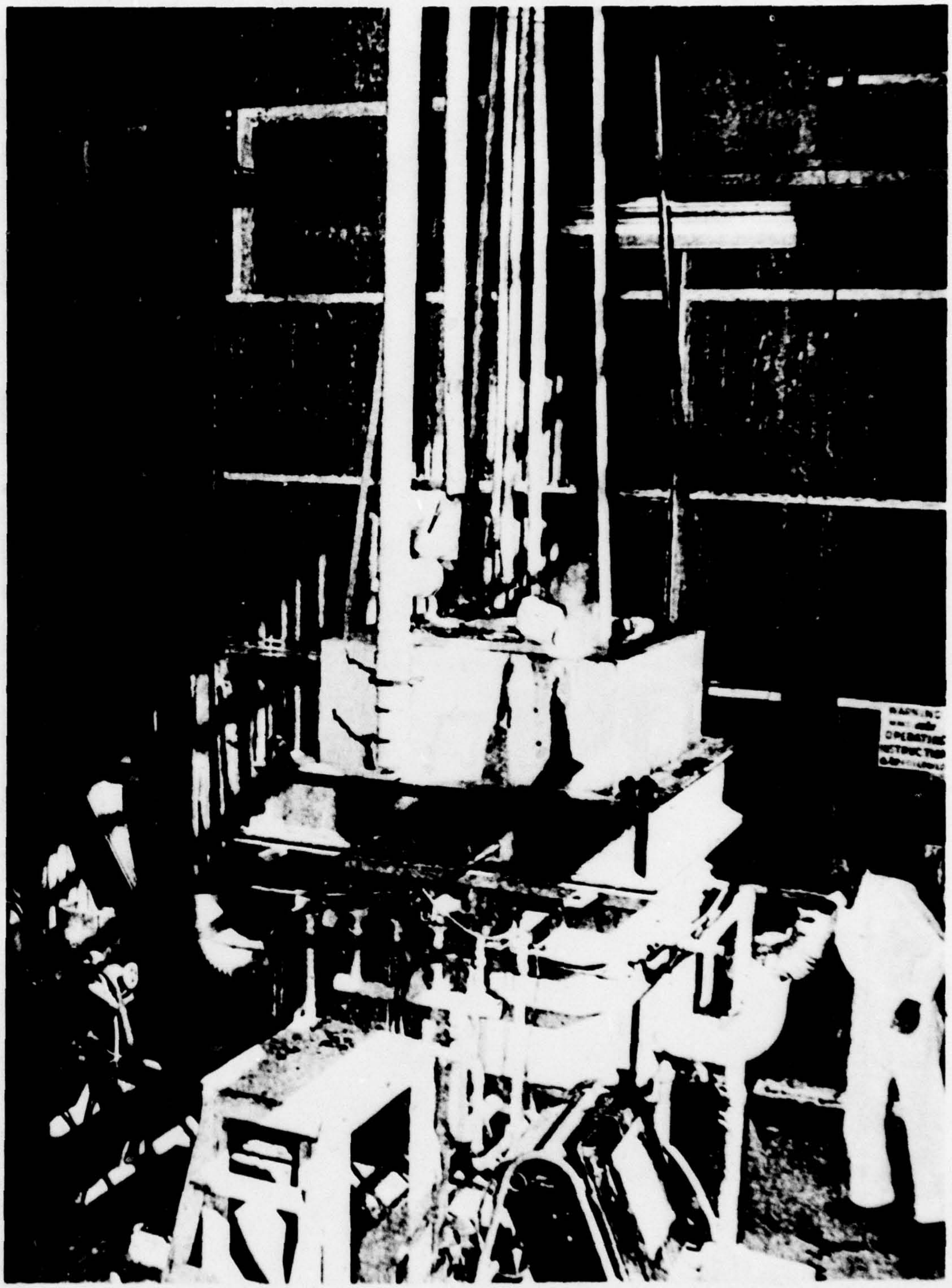


Figure A20. A view at the conclusion of the Australian test of May 26, 1975.

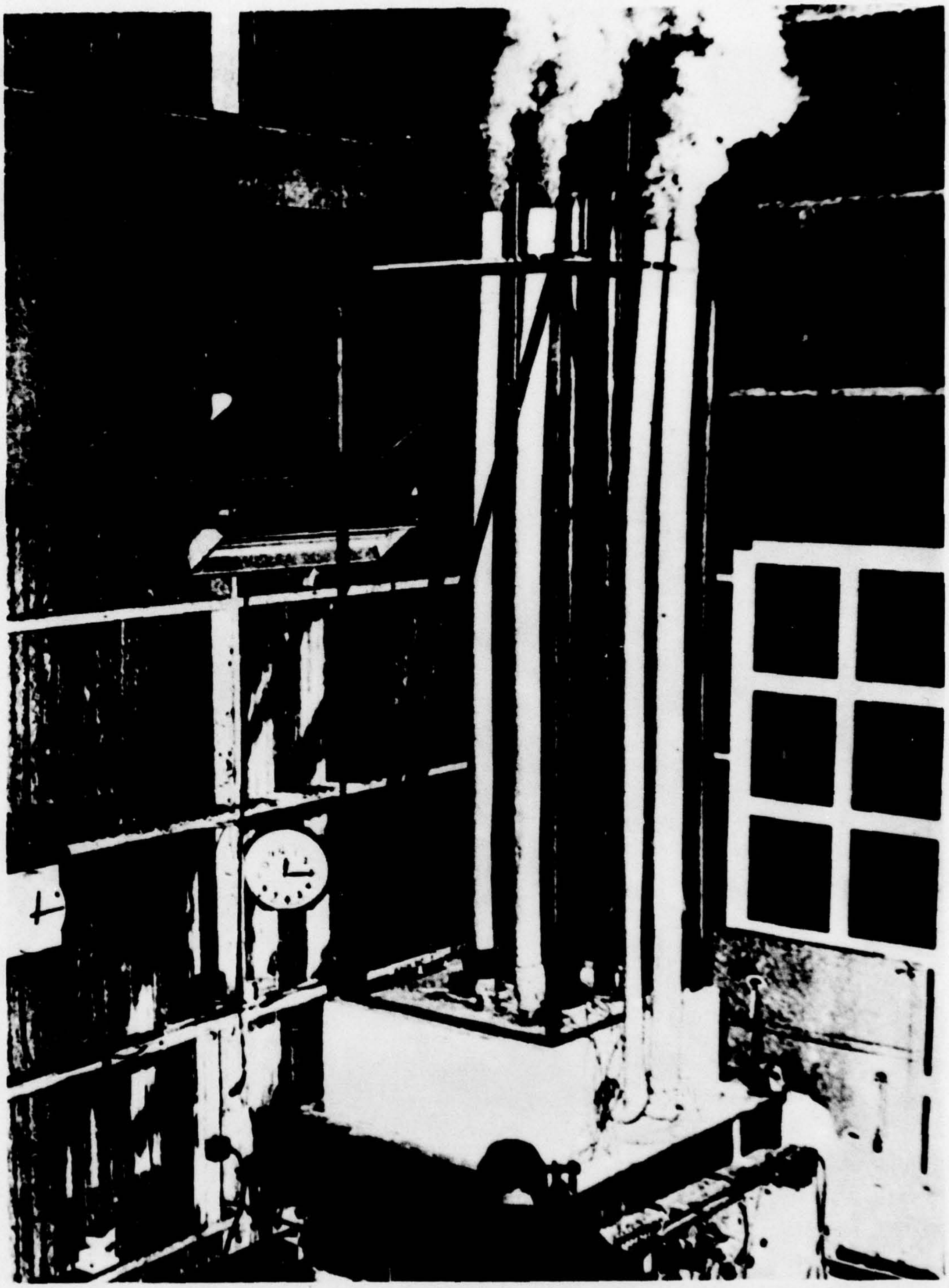


Figure A21. A view of the Australian test conducted on July 21, 1975 at approximately 15 minutes. Note there is some softening of the PVC pipes and there is smoke issuing from each vent. It should be recognized that plumbing systems are normally trapped within the buildings, and thus the smoke visible in this photograph would be vented outside the building under actual fire conditions.

Figure A22. At approximately 30 minutes into the July 21st test, there was collapse of one pipe and considerable softening of the other pipes. Note that one pipe has fallen away from the sidewall and left an open hole.

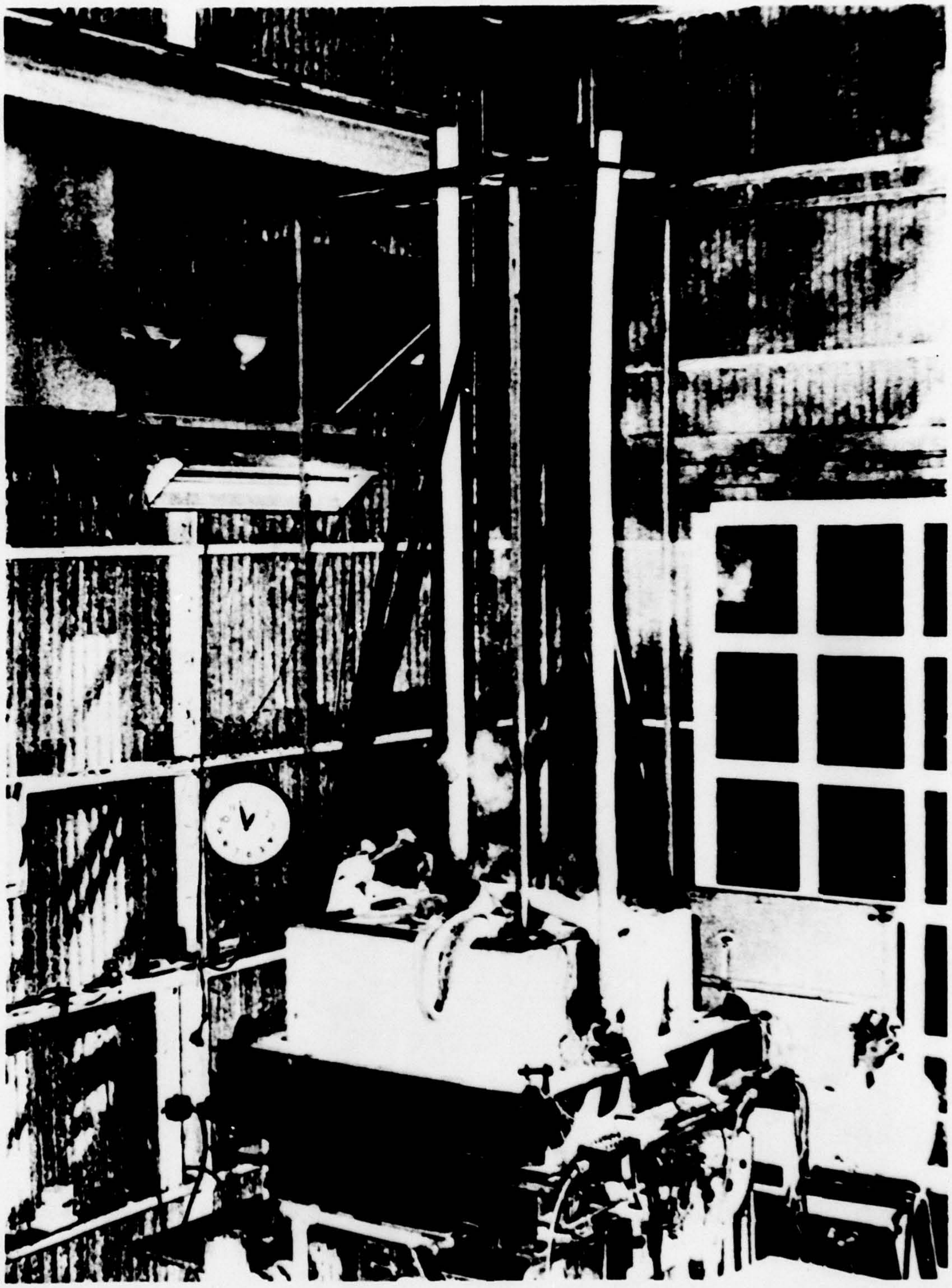


Figure A23. Near the conclusion of the 55-minute-long test performed on July 21.

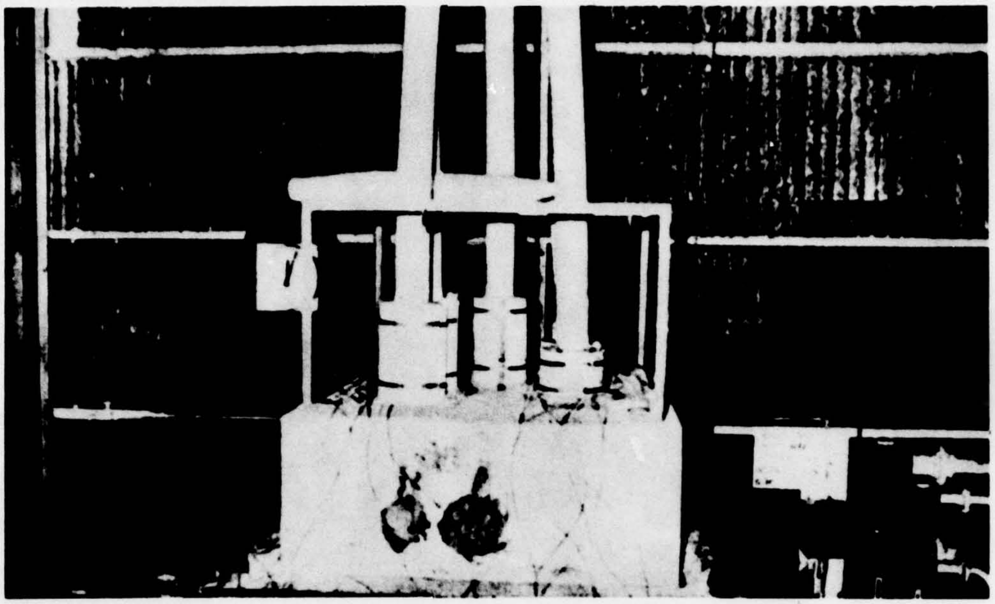


Figure A24. PVC pipes and fittings shortly after the commencement of the test conducted on September 15, 1975.

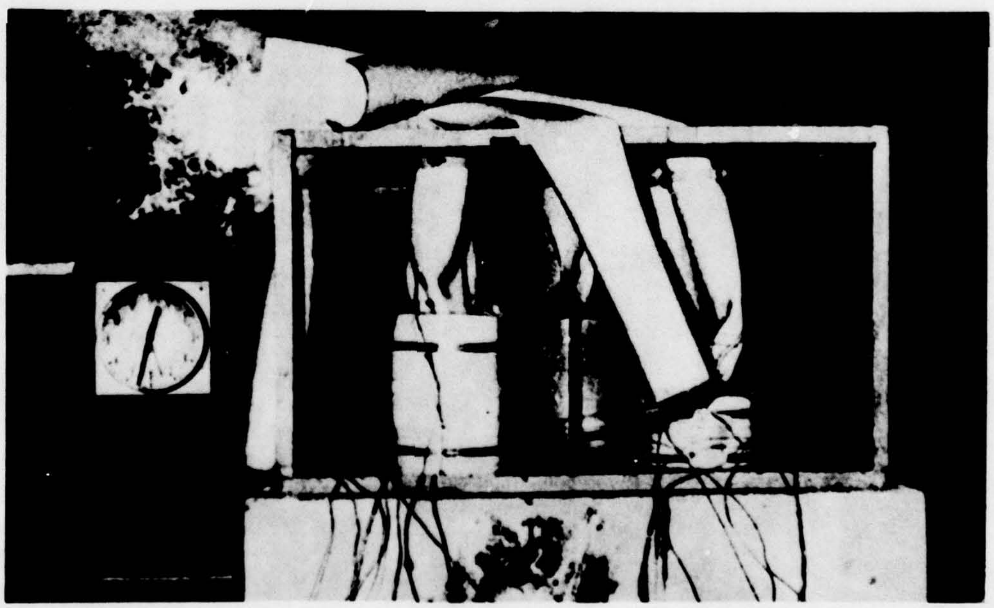


Figure A25. After 32 minutes of the September 15th test. Note the collapse of the pipe; however, the steel frame prevented the complete sealing of the pipe.

ANNEX 1

The following reports have been reviewed, but have not been explicitly included in the text of the report.

1. *An Investigation on the Fire Spread Potential of ABS Plastic DWV Pipe Installations* by I.A. Benjamin and W.J. Parker, NBS Report 10342 September 1970 (later summarized in *Fire Technology*).

   This is the precursor to the NBS research [4] described in section 4 of the appendix. There were two Chase Tests similar to those listed in Table A1.

2. *Fire Tests Concerning the Penetration of Walls by Horizontal Plastic DWV Pipes* by J.H. McGuire and P. Huot. National Research Council of Canada Technical Note 557, January 1971.

   This is essentially the same work later reported by McGuire [2]. They made the conclusion, "It would appear, for most pipe/wall combinations, that fire propagation is unlikely provided the pipe is adequately sleeved and it is closed (for example by a trapped fixture) at some location beyond the unexposed surface of the wall."

3. "Fire Valve"
   R. and G. Sloane Manufacturing Co.
   7606 North Clybourn Ave.
   P.O. Box 876
   Sun Valley, CA 91352
   (213) 767-4726

   There are three U.S. Patents on devices to sever plastic pipe where it passes through a fire exposed wall or floor by guillotine action. The abstracts to these patents are as follows:

   a. U.S. Patent 3,462,890, Aug. 26, 1969, "Plastic Article Severing and Insulating Apparatus."

      James J. Blumenkranz, Hollywood, and Eugene H. Wise, Saugus, Calif., assignors to The Susquehana Corporation, Fairfax County, Va., a corporation of Delaware.

      Abstract of the Disclosure

      Apparatus for severing and insulating a plastic article such as a pipe section extending through a fire-resistant wall or floor to prevent the spread of fire by the progressive burning of the pipe section. The apparatus generally comprises a slidably movable, fire-resistant blade or baffle assembly which cuts through the plastic pipe section to interrupt it when it softens in the presence of fire and before it ignites, and baffles or screens the open pipe section end, thereby insuring against the spread of fire via the pipe section from the hot side to the cold side of the fire-resistant wall or floor.

   b. U.S. Patent 3,678,634, July 25, 1972, "Fire Isolation and Insulating Apparatus."

      Inventors: Eugene H. Wise, Saugus; James J. Blumenkranz, Hollywood, both of Calif.
      Assignee: R & G Sloane Manufacturing Company, Inc., Los Angeles, Calif.

      Abstract

      Apparatus for closing off and insulating a plastic article such as a pipe section extending through a fire-resistant wall or floor to prevent the spread of fire by the progressive burning of the pipe section. The apparatus generally includes a slidably movable gate, preferably metal, which seals the walls of the plastic pipe section to interrupt it when it softens in the presence of fire and before it ignites, and baffle or screen the pipe section, thereby insuring against the spread of fire via the pipe section, such as from the hot side to the cold side of the fire resistant wall or floor. Such apparatus may be installed on either or both sides of the wall or floor through which the plastic pipe section passes.

      17 Claims, 10 Drawing Figures

   c. U.S. Patent 3,726,050, Apr. 10, 1973, "Fire Prevention Device."

      Inventors: Eugene H. Wise, Newhall; Alden E. Friend, Arleta, both of Calif.
      Assigneee: R & G Sloane Manufacturing Company, Inc., Los Angeles, Calif.

      Abstract

      Apparatus for preventing the spread of fire in a plastic article such as a pipe section extending through a fire-resistant wall or floor is hereby disclosed. The apparatus generally includes a sleeve member which surrounds the plastic pipe extending through the wall, the sleeve being provided with a shutter device which is pivotally mounted on the sleeve and which is biased against the plastic pipe so that the shutter serves to block the passage through the sleeve member

when the pipe is sufficiently softened in the presence of fire. The shutter device may be any of several configurations including a flapper valve or a rotary plate construction. Such apparatus may be installed on either or both sides of the wall or floor through which the plastic pipe section passes.

17 Claims, 6 Drawing Figures

Figure 1A1 shows two sketches of fire valves made by James J. Blumenkranz of R. and G. Sloane Co. There were nine separate fire tests representing the evaluation of 29 different fire valve units. In a personal communication to the author Mr. Blumenkranz commented as follows:

"The cast iron versions worked very well except that in many cases the temperature of the metal valve frame on the cold side of the wall exceeded the E119 temperature limit. As this situation was acceptable to the State Fire Marshall's Office at that time, I called the test results a success if the device prevented a flame through."

Photographs of these units are shown in Figures 1A2 and 1A3.

4. "A Full-scale Fire Test of a Wall Penetrated by Plumbing Facilites," by J.H. McGuire, Building Research Note 97. National Research Council of Canada, December 1974.

A full-scale fire test, under a positive pressure of 0.2 in. W.G., was carried out on a wall/floor assembly penetrated by a 3-in. ABS DWV pipe. A toilet fixture, mounted on a 3½ in. concrete floor section, was exposed to the furnace and the associated ABS pipe passed through the floor and then through the wall. The section of pipe preceding the wall penetration, although within a fire-resistant enclosure, was nevertheless destroyed during the course of the 2-hour test. The wall penetration remained intact, however, by virtue of pipe collapse on the unexposed side of the wall.

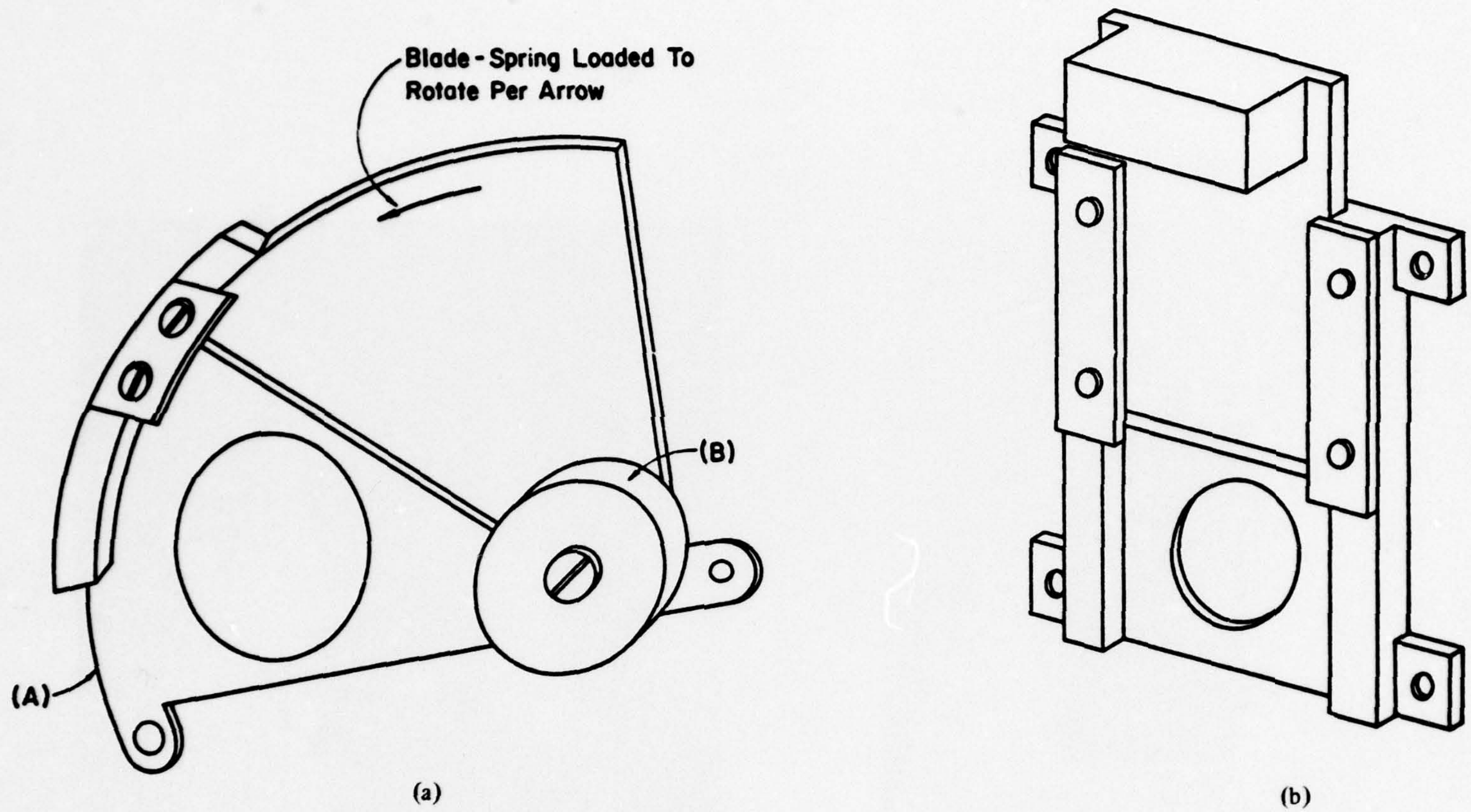


Figure 1A-1. Schematic diagram of the R. and G. Sloane "Fire Valves"

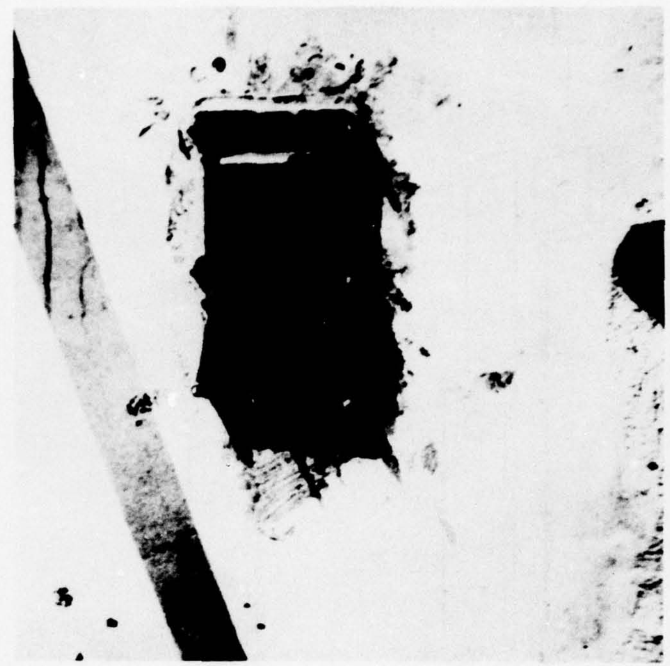
(a) Vertical Slide, Gravity Loaded Cast Iron Fire Valve, for use in walls.

(b) Horizontal Slide, Spring Loaded Cast Iron Fire Valve. Protects vertical penetrations through floors.

(1) Base Plate fastened to floor.

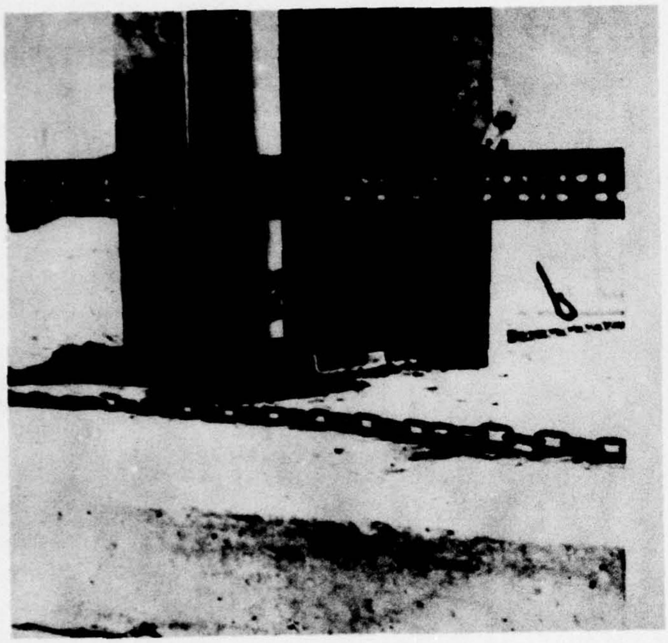
(2) Torsion Spring Housing.

(a)

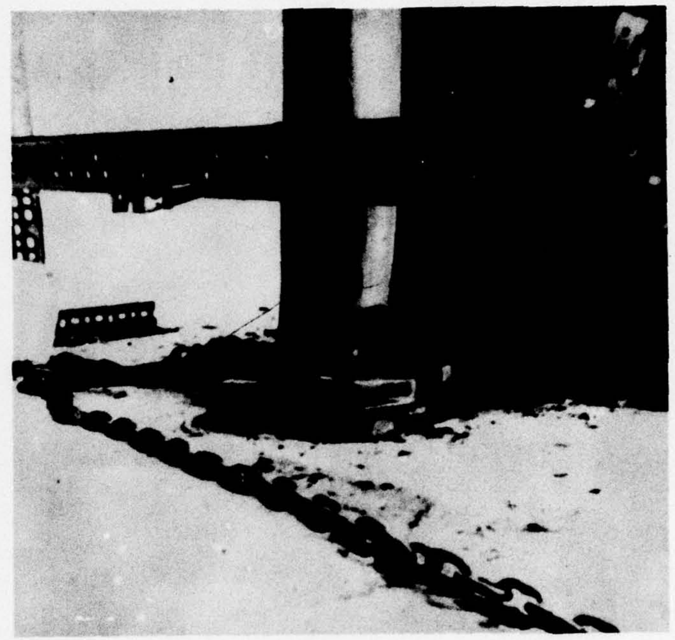


(b)

Figure 1A-2. Vertical Fire Valve Installed in Furnace Wall
(a) Unexposed face during test showing guillotine action of valve on pipe.
(b) After test the pipe has been moved and it is apparent that the valve has closed the gap in the wall.



(a)



(b)

Figure 1A-3. Horizontal Fire Valve Installed in Furnace Roof
(a) Shows unexposed face before test.
(b) Shows guillotine action on plastic pipe during test.

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63 p. : ill. ; 27 cm. (Technical report ; M-264)

1. Pipe, plastic. I. Williamson, R. Brady. II. Title. III. Series: U.S. Construction Engineering Research Laboratory. Technical report ; M-264.